EVALUATION OF ORGANOPHOSPHATE INSECTICIDES ON PERFORMANCE OF TRANSGENIC AND CONVENTIONAL COTTON

A Thesis

by

CHRISTOPHER ALAN HUNDLEY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2004

Major Subject: Agronomy

EVALUATION OF ORGANOPHOSPHATE INSECTICIDES ON PERFORMANCE OF TRANSGENIC AND CONVENTIONAL COTTON

A Thesis

by

CHRISTOPHER ALAN HUNDLEY

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Approved as to style and content by:

_____	_____
J. Tom Cothren (Chair of Committee)	Frank M. Hons (Member)
_____	_____
Stephen W. Searcy (Member)	Mark A. Hussey (Head of Department)

May 2004

Major Subject: Agronomy

ABSTRACT

Evaluation of Organophosphate Insecticides on Performance of

Transgenic and Conventional Cotton. (May 2004)

Christopher Alan Hundley, B.S., Texas A&M University

Chair of Advisory Committee: Dr. J. Tom Cothren

Genetically modified cotton (*Gossypium hirsutum* L.) acreage has increased dramatically over the last six years. Reports of variable results in fiber quality and yield have arisen in these cultivars. Some changes in production practices have occurred coincident with the introduction of transgenic technology, such as reduced use of broad-spectrum insecticides, including organophosphates (OP) that could potentially influence the growth and yield of cotton. One factor that might affect these parameters is the difference in the amount of foliarly-applied phosphorus (P) between an OP and non-phosphate (NP) insecticide regime. Therefore, a study was conducted to investigate selected growth characteristics, yield, and fiber quality of genetically modified and conventional cotton as influenced by OP and foliar phosphorus (FP) applications.

A four replication strip-plot experimental design was utilized with cultivar serving as the whole plot and insecticide regime as the sub-plot. Three cultivars of the same recurrent parent (ST4892BR, ST4793R, and ST474) were planted in 2001 and 2002 under irrigated conditions in Burleson County, TX on a Weswood silty clay loam (fine-silty, mixed, thermic Fluventic Ustochrept). The insecticide regime consisted of

NP, NP+FP, and OP treatments. The FP was applied at P_2O_5 weight equivalent to the P component in the concurrent OP application.

ST4892BR had greater lint yield than ST4793R and ST474. The yield increase can be explained through plant mapping analysis which showed ST4892BR producing larger bolls and greater boll numbers. In addition, evaluation of fruiting distribution showed ST4892BR contained more lint on sympodial branches 6 through 10. The insecticide regime effect on lint yield resulted in higher yield (P=0.08) for the NP+FP regime. Examination of yield components revealed NP+FP increased second position bolls, predominantly at sympodial branches 6 through 10. Leaf tissue analysis revealed increased levels of P for the OP and NP+FP over that of the NP insecticide regime, which indicates a potential for plants to acquire P from OP insecticides. Furthermore, the considerable yield response to small amounts of FP is not clearly understood. While conclusive evidence exists regarding cultivar yield differences, this study does not provide sufficient evidence to conclude that OP insecticides influence growth, yield, or fiber quality characteristics of these cotton cultivars.

DEDICATION

This thesis is dedicated to my loving wife, Leah, whose unconditional love, patience, and support gave me the strength and drive to complete this degree.

ACKNOWLEDGEMENTS

I would like to extend appreciation to the following individuals and organizations for their support, input, and guidance that made it possible for me to complete the requirements for this degree.

My graduate committee is recognized for their advice and assistance throughout this research project and graduate curriculum. The Department of Soil & Crop Sciences and Department of Biology at Texas A&M University, the Texas Agricultural Experiment Station, Biological Research Service, Inc., Buffalo Ranch, T-Systems International, Inc., and Stoneville Pedigreed Seed are acknowledged for their financial support and material contributions.

The following individuals did not serve on my graduate committee but provided support and enriched my educational experience: Dr. C. Wayne Smith, Texas A&M University; Dr. Scott Senseman, Texas A&M University; Dr. Michael Speed, Texas A&M University; Dr. Ty Witten, Monsanto Corporation; Mr. Jess McCrory and Mr. Jimmy Killebrew, Buffalo Ranch; and Mr. Roger Horn, Texas A&M University.

I would also like to extend thanks to the Cotton Physiology Workgroup at Texas A&M University for their hard work and generosity in accomplishing field research tasks. Thanks are also given to my sisters, Denise and Lauren, for assisting me with this project. My wife, Leah Hundley, is especially appreciated for all the afternoons and evenings spent assisting me in collection of scientific data for this study.

Special appreciation is extended to Dr. J. Tom Cothren, the chair of my graduate committee, for his patience, generosity, and unwavering support throughout my academic and research endeavors.

Finally, I would like to thank my parents, Mike and Linda Hundley, for instilling a solid work ethic and drive in me from a young age. Their continuous support and love have provided the tools needed to complete this degree.

TABLE OF CONTENTS

Page

LIST OF FIGURES

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

LIST OF TABLES

INTRODUCTION

Pest management in cotton (*Gossypium hirsutum* L.) constitutes a major challenge for the production of a successful crop. Beginning early in the growing season, producers put forth great efforts to minimize weed competition and insect pressure. This challenge ensues for the duration of the cotton growing season. With the evolution of technology, the agronomic world encountered a valuable tool: transgenic technology. With the advent of this technology, producers could make broad-spectrum herbicide applications to a once vulnerable crop now equipped with the insertion of the Roundup Ready® gene. Insect management was also redefined through the implementation of a new tool.

In the late 1980's, Monsanto began development of Bollgard® (*Bt)* insect-protected cotton by transformation with a construct containing the *cry*1Ac gene from *Bacillus thuringensis* var. *kurstaki*, a naturally occurring soil bacterium (Peferoen, 1997; Adkisson et al., 1999). When target pests, such as key lepidopteran species, ingest the toxin, the *Bt* protein interferes with the insect's digestive system and causes death.

Due to the onset of this technology, the seed market has experienced a shift in the demand between conventional and transgenic cultivars. Genetically modified cotton hectarage has increased dramatically over the last six years. In 2002, Texas planted 1.2 million genetically modified cotton hectares and U.S. hectarage reached 4.3 million (NASS, USDA Agricultural Statistics, 2002). Upland cotton planted in Texas, encompassing all technology types, totaled 5.6 million hectares in 2002. Concern has

---

This thesis follows the style and format of Crop Science.

been expressed recently by many segments of the industry regarding yield and quality trends for some regions of the U.S. Cotton Belt (Kerby et al., 2002).

Reports of variable results in fiber quality and yield have arisen in genetically modified cultivars. Bryant et al. (2000), in conjunction with the University of Arkansas, have conducted economic evaluations of transgenic cotton systems since 1996. In 2000, Bryant et al. reported mixed results regarding yield depending on the year of comparison, cultivars involved, location, and the management practices utilized. For example, evaluation of Bollgard® cultivars at the Southwest Arkansas location resulted in a positive change in profit every year, with the exception of one observation. Six cultivars were evaluated at the Southeast Arkansas location, resulting in a conventional cultivar producing yields and returns that were statistically greater than the remaining cultivars. A stacked-gene cultivar at that location resulted in significantly less yield and return than the other five cultivars. All six cultivars at the Northwest Arkansas location resulted in non-significant differences. Evaluation at the South Central and Central Arkansas locations resulted in Bollgard® cultivars having negative changes in profit (resulting from lower yield). In 1997, ReJesus et al. conducted a study on the economic analysis of insect management strategies for transgenic *Bt* cotton production at two locations in South Carolina. This study found that one location resulted in higher actual experimental yield for *Bt* cotton than non-*Bt* cotton though statistical analysis exhibited no significant differences between the two sites. Lege' et al. (2001) found no consistent trends for lint yield, staple length, fiber strength, or micronaire with regard to technology type, which parallels conclusions of Kerby et al. (2000) and Ethridge and Hequet (2000).

Some studies have shown insecticides to exhibit plant growth regulator properties. In 1990, Bauer and Cothren reported the effects of chlordimeform, [*N*'-(4-chloro-o-tolyl)-*N*,*N*-dimethylformamidine], on the physiological activity of radish (*Raphanus sativa* L.) seedlings. This study showed chlordimeform to possess growth promoting characteristics similar to the natural plant hormone, cytokinin. Another study, conducted by Reddy et al. (1997), involved the plant growth regulator characteristics exhibited by a member of the carbamate class of insecticides. In 1997, Reddy et al. showed that aldicarb [2-methyl-2-(methylthio)propionaldehyde O-(methylcarbamoyl)oxime] increased early season vegetative growth of cotton at certain day/night temperature combinations. Other results indicated that the treated plants had increased root growth, greater root length densities, and higher root/shoot ratios than control plants at all temperature ranges. Summary results for this study showed that aldicarb promoted cotton earliness by enhancing growth rates and promoting deeper root penetration into the soil.

Some changes in production practices have occurred coincident with the introduction of transgenic technology, such as reduced use of broad-spectrum insecticides including organophosphates (OP), as well as less cultivation (Edge et al., 2001), that could potentially influence the growth and yield of cotton. One factor that might affect these parameters is the difference in the amount of foliarly-applied phosphorus (P) between an OP and non-OP insecticide regime. The reduced use of broad-spectrum OP insecticides negates any beneficial effects the P component common to the chemical structure of all OPs have on the plant. Considered a macronutrient, P is

an integral component of key compounds of plant cells. This includes the sugar-phosphate intermediates of respiration and photosynthesis, and the phospholipids that make up plant membranes (Taiz and Zeiger, 1998). It is also a component of nucleotides used in plant energy metabolism and in DNA and RNA (Taiz and Zeiger, 1998). Adenosine di- and triphosphates (ADP and ATP) act as "energy currency" within plants (Havlin et al., 1999). When the terminal phosphate molecule from either ADP or ATP is split off, a relatively large amount of energy (12,000 cal mol^{-1}) is liberated (Havlin et al., 1999). Energy obtained from photosynthesis and metabolism of carbohydrates is stored in phosphate compounds for subsequent use in growth and reproductive processes (Havlin et al., 1999). Almost every metabolic reaction of any significance proceeds via phosphate derivatives (Havlin et al., 1999). Because of its vital role in biological functions within the plant, P deficiencies can have a major impact on plant health. Plants uptake P by absorbing either $H_2PO_4^-$ or HPO_4^{2-} orthophosphate ions, with $H_2PO_4^-$ absorption greatest at low pH values and HPO_4^{2-} greatest at higher soil pH values (Havlin et al., 1999). Plants may also absorb certain soluble organic phosphates; however, their importance as sources of P for higher plants is limited (Havlin et al., 1999). Phosphorus is one of the least available of all essential nutrients in the soil and its concentration is generally below that of many other micronutrients (Barber et al., 1963). Additionally, because of the unique interaction of P with other elements, up to 80% of applied P may be fixed in the soil (Barrow, 1980; Holford, 1997). A study was conducted in Pakistan to determine the effect of P on growth, yield, and fiber quality of two cotton cultivars. The results of this study showed a significant increase in seed

cotton yield due to P fertilizer application (Makhdum et al., 2001). Nelson (1949) studied cotton under conditions of a yield response to applied nutrients and reported increased seedcotton yields with soil-applied P applications of up to 56 kg P_2O_5 ha^{-1}. However, Hons et al. (1990a) conducted a study on a soil testing high in available P and reported that soil-applied P had no influence on lint or seed yields.

Research has shown that cotton uptakes approximately 17 to 19 kg P ha^{-1} during the growing season, depending on soil type (Bassett et al., 1970; Mullins and Burmester, 1990). Olson and Bledsoe (1942) reported that mature cotton plants grown on three soil types removed 4.4 kg P 100 kg^{-1} lint produced. Work by Bassett et al. (1970) found mature plants contained 1.3 kg P 100 kg^{-1} lint for irrigated cotton in California, while Halevy (1976) reported 2.6 to 2.7 kg P 100 kg^{-1} lint produced from two cotton cultivars under irrigated conditions in Israel. Bassett et al. (1970) reported that the removal of P from the field at harvest was 9 to 12 kg ha^{-1} in the seed, which represents between 52 and 62 % of the total P recovered from mature plants. The work of Mullins and Burmester (1990), who reported approximately 52.8 % of total plant P was distributed within the seed, supports the findings of Bassett et al. (1970). Furthermore, Bassett et al. (1970) found that the P content of seed was approximately 0.56 to 0.61 % P. Olsen and Bledsoe (1942) reported P accumulation within the plant peaked from 90 to 105 days after emergence. During this period a maximum accumulation rate of 0.74 kg P ha^{-1} d^{-1} was reached with cotton grown on a Cecil soil (clayey, kaolinitic, thermic Typic Hapluduts).

Due to the large quantity required by plants, foliar feeding of P has generally not been found to be practical. This is primarily because frequent application of small amounts is required to avoid injury to the leaves. Lancaster and Savatli (1965) found that solutions of monoammonium and of sodium polyphosphate (mixture of orthophosphoric acid and sodium pyrophosphate) containing as little as 1.5 % P_2O_5 caused some leaf injury. Careful consideration must be made regarding the strength of solutions for foliar application. Some research has shown potential for yield increases from foliar P applications; however, results have been variable. Lancaster and Savatli (1965) reported that foliar application of P during the latter part of the fruiting period at one location did not increase yield, while at another location, a yield increase was observed. Other work, as reported by Kuepper (2003), has shown potential benefits related to the increased uptake of additional nutrients from the soil as a response to foliar fertilization. Kuepper (2003) contends that the logic behind this theory is based on the belief that foliar fertilization causes the plant to pump more sugars and exudates from its roots into the rhizosphere. The increased availability of these exudates stimulates beneficial microbial populations in the root zone. The enhanced biological activity potentially results in greater availability of nutrients, disease suppressive biochemicals, vitamins, and other beneficial constituents conducive to plant growth.

OBJECTIVES

Studies were conducted over a three-year period with field and greenhouse experiments in accordance to the following objectives: (i) to ascertain if the organophosphate class of insecticides exhibit plant growth regulator characteristics, (ii) determine the effects of foliar phosphorus and organophosphate applications on selected growth parameters, yield, and fiber quality (iii) evaluate differences in cultivar response to foliar treatments, and (iv) assess variations in yield and fiber quality of genetically modified and conventional cotton.

MATERIALS AND METHODS

FIELD STUDY

A four replication strip-plot experimental design was utilized with cultivar serving as the whole plot and insecticide regime as the sub-plot. A strip-plot is like a split-plot experimental design but with differently constructed experimental units (Milliken and Johnson, 1992). The subunit treatments are applied in strips across an entire replication of main plot treatments. In the case of this study, the strip-plot design was chosen for practicality considerations regarding foliar treatment application and drift concerns. The study was sectioned into four quadrants, each making one repetition. Each repetition was surrounded on two sides with an eight-row border of FiberMax 989BR cotton. A 7.62-m alleyway was located at the front and back sides of each repetition. It was necessary to incorporate this degree of spatial separation to prevent drift contamination of treatments during application. The experimental design provided for nine treatments with a total of 36 four-row test plots 15.24 m in length.

Three cotton cultivars of the same recurrent parent (cv. Stoneville Pedigreed Seed (ST): ST4892BR, ST4793R, and ST474) were planted April 11, 2001 and 2002 on 1.02 m row-spacing at uniform populations under irrigated conditions in Burleson County near College Station, TX. ST4892BR represents the Bollgard® + Roundup Ready® stacked-gene cultivar, ST4793R is the Roundup Ready® cultivar, and ST474 represents the conventional cultivar. ST4892BR and ST4793R are transgenic cultivars and ST474 is the recurrent parent of the two transgenic lines. The soil type, classified as Weswood silty clay loam (fine-silty, mixed, thermic Fluventic Ustochrept), is an alluvial

soil in the Brazos River floodplain. The insecticide regime (IR) consisted of three unique application regimes. In the first regime, all insecticides consisted of the organophosphate OP group, which served as the phosphate-based insecticide application. The second regime utilized applications of non-phosphate (NP) insecticides and served as an experimental control. The third regime (NP+FP) consisted of NP plus additional foliar phosphorus (FP) applied as 12-48-08, in the form of a water soluble fertilizer (RSA MicroTech, LLC, Marysville, WA). The 12-48-08 fertilizer utilized ammonium phosphate as a source of P. The FP was applied at an equivalent P_2O_5 weight as the concurrent OP application. To calculate the amount of FP to apply as P_2O_5, the amount of the P component contained in an individual OP insecticide was ascertained from the chemical formula for each of the OP insecticides used. Recommended insecticide rates, attained from the chemical label, were followed for each application on all regimes. Nine applications of this IR were made during the season at key phenological stages commencing with pinhead square through ten percent open bolls (Table 1). The rates for each of the nine IR applications are listed in Table 2.

Specific definitions were followed to assess the stage of growth for the IR treatment timings. Pinhead square and matchhead square occur when the size of squares on the cotton plant are equivalent to the size of a pinhead and matchhead, respectively. First bloom was determined by the appearance of at least one white flower in the study. Early bloom was marked by the appearance of 5 to 6 white flowers per 7.62 m of row. Mid-bloom period was defined by approximately 3 weeks of flowering (Ohlendorf et al., 1996). Peak bloom was determined by counting the number of white flowers per 7.62 m

Table 1. Timing of insecticide regime (IR) applications with corresponding phenological stages of cotton growth.

IR Application Number	Stage of Growth
1	Pinhead Square
2	Matchhead Square
3	First Bloom
4	Early Bloom
5	Mid-Bloom
6	Peak Bloom
7	Cutout
8	First Open Boll
9	10 % Open Bolls

Table 2. Insecticides and corresponding rates composing insecticide regime (IR) treatments for each of nine applications (APP).

	IR Treatment†		
APP	NP	NP+FP‡	OP
1	Capture® 2EC (0.30 L ha^{-1})	12-48-08 (0.13 kg ha^{-1})	Guthion® 2L (1.17 L ha^{-1})
2	Capture® 2EC (0.30 L ha^{-1})	12-48-08 (0.13 kg ha^{-1})	Guthion® 2L (1.17 L ha^{-1})
3	Capture® 2EC (0.30 L ha^{-1})	12-48-08 (0.13 kg ha^{-1})	Guthion® 2L (1.17 L ha^{-1})
4	Capture® 2EC (0.30 L ha^{-1})	12-48-08 (0.13 kg ha^{-1})	Guthion® 2L (1.17 L ha^{-1})
5	Fury® 1.5EC (0.22 L ha^{-1})	12-48-08 (0.26 kg ha^{-1})	Bidrin® 8 (0.44 L ha^{-1})
6	Fury® 1.5EC (0.22 L ha^{-1})	12-48-08 (0.33 kg ha^{-1})	Curacron® 8E (0.88 L ha^{-1}) Fury® 1.5EC (0.15 L ha^{-1})
7	Fury® 1.5EC (0.22 L ha^{-1})	12-48-08 (0.33 kg ha^{-1})	Curacron® 8E (0.88 L ha^{-1}) Fury® 1.5EC (0.15 L ha^{-1})
8	Fury® 1.5EC (0.22 L ha^{-1})	12-48-08 (0.33 kg ha^{-1})	Curacron® 8E (0.88 L ha^{-1}) Fury® 1.5EC (0.15 L ha^{-1})
9	Fury® 1.5EC (0.22 L ha^{-1})	12-48-08 (0.44 kg ha^{-1})	Curacron® 8E (0.1.17 L ha^{-1})

†The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

‡The quantity listed represents the amount of fertilizer product applied.

of row. The point at which the white flower count is highest before declining is designated as peak bloom. Cutout occurs when the cotton reaches 5 average nodes above the first position white flower (Oosterhuis et al., 1996). The first open boll stage of growth was determined by at least 50 percent of the plots in the study having an open boll (Ohlendorf et al., 1996). The 10 percent open boll stage was determined by conducting open and closed boll counts throughout the field and calculating the percent of open bolls.

All border rows were treated with NP at every IR spray interval. The Boll Weevil Eradication Program was in progress concurrent with the study dates and locale for this experiment. This presented a unique challenge in maintaining the integrity of the experiment. Because the Program uses Malathion ULV (O,O-dimethyl phosphorodithioate of diethyl mercaptosuccinate), an OP material, collaboration was necessary to meet their treatment requirements and timings to preclude IR adulteration. In response to this and other pest concerns, broadcast NP applications were made, outside of the IR protocol, to all treatments as called for by scouting results based on threshold levels for the conventional cultivar to minimize pest pressure (Appendix A). All field plots were subjected to seed treatment with Gaucho® 480 (5.2 ml kg^{-1}), and Temik® 15G (4.48 kg ha^{-1}) was applied in-furrow at planting.

Determination of residual macronutrients at the test site was acquired through soil analysis. Prior to cotton planting, soil was sampled, at a depth of 15 to 20 cm, from plots and mixed to procure a uniform sample. The soil analysis was conducted by the Texas A&M University Soil, Water, and Forage Testing Laboratory located on the

Texas A&M University campus in College Station, TX. Determination of residual soil NO_3-N was based on methods by Keeney and Nelson (1982), while soil P_2O_5 and K_2O determinations were based on methods by Hons et al. (1990b). Residual NO_3-N, P_2O_5, and K_2O were 17.9, 430.6, and 1134.8 kg ha^{-1}, respectively. Cotton was seeded at a rate of 11 to 12 seed per meter of row, at a depth of 3.2 cm, using an eight-row John Deere Max-Emerge® planter. In 2001, irrigation was provided using a pivot overhead sprinkler system. Subsurface drip irrigation was installed before planting in 2002. The irrigation T-Tape® was provided by T-Systems International, Inc. The T-Tape® was placed on 2.03 m furrow centers throughout the study. Approximately 2 cm (pivot) and the equivalent of 2 cm (subsurface) of water was applied at each irrigation interval. All other maintenance inputs were based on current local agronomic practices. In addition to hand hoeing, chemical methods were used to control weeds. These chemicals are listed in Appendix A.

Applications of IR treatments were made using a Hahn® self-propelled boom sprayer equipped with two additional spray tanks. The sprayer control was modified to accommodate all three tanks. In addition, a flush valve and manifold were incorporated to prevent bypass and line contamination between treatments. The boom effectively covered twelve rows allowing three plots to be sprayed at one time. The spray nozzles used were Tee Jet® XR8002VS flat fan nozzles. Prior to spraying, all nozzles were calibrated to deliver within five percent of the targeted volume. All IR treatments were delivered at a volume of 93.5 L ha^{-1}.

Characteristic growth data collected during the growing season consisted of plant height and number of nodes (average of six randomly selected representative plants per plot), collected at biweekly intervals, commencing just prior to initial insecticide application. Stage of growth was evaluated in terms of nodes above white flower (NAWF). Measurements of NAWF were collected on six randomly selected representative plants per plot at mid-bloom [75 and 71 days after planting (DAP) for 2001 and 2002, respectively] and continued at weekly intervals until first open boll.

Biomass partitioning was assessed one week prior to peak bloom (85 and 81 DAP, in 2001 and 2002, respectively) to determine plant height, number of nodes, and fruiting and biomass distribution. Six representative plants were cut below the cotyledonary scars on the main stem from rows one and four of each plot, and after visual examination, the least uniform plant was discarded. Dry weight data for the resulting five plants were recorded for stems, leaves, squares, and bolls as well as counts for number of squares and bolls.

Tissue analysis was conducted to determine the concentration of P in the leaf tissue. Due to financial considerations, tissue analysis was conducted on two of the three cultivars. It was determined that samples would be taken from the transgenic stacked-gene and conventional cultivars, ST4892BR and ST474, respectively. At 114 and 116 DAP in 2001 and 2002, respectively, a total of ten leaves were removed at random from rows two and three of each plot, collectively. Criteria for collecting a sample leaf involved removing the fourth leaf below the plant terminal, counting at least a quarter-size terminal leaf as zero. Leaf petiole tissue was not included in the sampling.

The timing for tissue sampling occurred approximately 7 to 8 days after the eighth IR treatment. Consequently, the leaves chosen for removal were young terminal leaves at the time of the eighth IR treatment. In essence, this results in all sampled leaves being of approximately the same age, size, and IR exposure. The site for leaf removal in conjunction with the sampling date were chosen to provide sufficient time for the young terminal leaf, exposed to the target IR treatment, to mature to a reasonable sample size, yet permit removal prior to the following IR treatment. The leaf samples were analyzed for nutrient content by the Texas A&M Soil, Water, and Forage Testing Laboratory located on the Texas A&M University campus in College Station, TX. Determination of nutrient concentration in leaf tissue was based on methods by Feagley et al. (1994). The results of this procedure allow the determination of P concentration comparisons between the respective IR treatments. Evidence from this analysis is important to ascertain if FP uptake was observed from the NP+FP and OP treatments.

Plant mapping was conducted at harvest to determine plant height, number of nodes, and fruiting patterns at the conclusion of the growing season. The plant mapping technique and program constructed for this project were based on an adaptation of the methods developed by Landivar (1993) and Jenkins and McCarty (1995). On the day of, but prior to harvest, ten representative plants were removed from rows one and four of each plot. After visual examination, six uniform plants were selected for analysis. Boll distribution and seedcotton weight were recorded by sympodial zone (e.g. vegetative, 3-5, 6-10, 11-15, 16-20, and 21-25) and fruiting position. For the purposes of reporting plant mapping data, the sympodial zones are indicative of main-stem nodes counted

from the cotyledonary scars. The cotyledonary scars are counted as node zero. Fruit obtained from monopodial branches are included in the vegetative grouping. The predominant branch-type for the designated nodal groupings are sympodial (reproductive) branches. These data were imported into statistical software and program code was written to accommodate this data for analysis.

Harvest aids (Appendix A) were utilized in both years to prepare the crop for harvest. The application and timing of these chemicals were based on current local agronomic practices. Harvest aids were applied when the crop averaged 60% open bolls. Yield in 2001 and 2002 was acquired through the use of a two-row spindle cotton picker. Cotton was harvested from the two center rows in each plot and collected into burlap sacks via a modified chute system. Due to machine complications in 2002, only one center row was harvested. The entire length of 15.24 m was harvested for yield calculations. As a cautionary measure, between plots, the spindle and blower mechanism was operated, absent of cotton, to clear chutes of remaining seedcotton. The blower chutes were also visually checked and cleared, if necessary, to prevent cross plot contamination of seedcotton. If any cotton was collected during this process, it was placed in the sack for the respective plot. During harvest operations, seedcotton weight for each sack was recorded using a calibrated load cell connected to a computer. The sack weight was recorded in electronic and hardcopy forms. Empty weights of all burlap sacks were recorded and sacks were assigned unique plot identification numbers prior to harvest. This data was used to calculate actual seedcotton yield on a hectare basis for each plot. Following documentation of seedcotton weights, sub-samples were collected

to determine percent ginout and lint yield. A small saw-type, hand-fed, 10-blade research gin (Dennis Manufacturing, Inc., Athens, TX) was used to separate lint and seed. Lint obtained from the sample was weighed and divided by initial seedcotton weight to determine percent ginout. This data was subsequently used to calculate total lint yield per hectare. A 50 g sub-sample of lint from each plot was acquired and sent to the Texas Tech University International Textile Center, in Lubbock, Texas, for High Volume Instrument (HVI) testing to determine lint quality characteristics for each sample. Treatments effects on lint quality were determined from HVI data.

Statistical analysis was conducted on all appropriate data presented in this document. Some exploratory analysis of data was performed through the use of SPSS® (version 11.01) statistical software for computer systems running the Windows® platform (SPSS Inc., 1989-2001). In particular, the SPSS® software was used for developing profile plots, examination of homogeneity and normalcy of residuals, and statistical model development and comparison. The SAS® (version 8.1) statistical software was used for all final data analysis (SAS Institute, 1999-2000). Data was subjected to the Mixed Models Procedure with degrees of freedom estimated using the Satterthwaite approximation (Satterthwaite, 1946). Means were separated by the Tukey-Kramer procedure to determine statistical differences at α=0.05 significance level, unless otherwise noted. In the absence of year interactions, data for the 2001 and 2002 studies were combined. All graphical displays of data in this document were produced with Microsoft® Excel® 2002 (version 10.4302.4219-SP-2) spreadsheet software (Microsoft Corporation, 1985-2001).

GREENHOUSE STUDY

A greenhouse study was conducted to evaluate selected parameters under controlled conditions. The greenhouse provided an environment where the effect of differences in the efficacy of NP and OP insecticides on insect pressures could be minimized. Three cotton cultivars (cv. Stoneville Pedigreed Seed: ST4892BR, ST4793R, and ST474) were potted in one hundred and eight individual 18.9-L pots. The study utilized Metro-Mix™ 200 (Scotts-Sierra Horticultural Company, Marysville, OH) as a growing medium. The study was comprised of four replications of nine treatments in a strip-plot experimental design. Cultivar served as the whole plot, and foliar IR treatment composed the sub-plot. Each plot in this experiment was composed of three plants to allow for harvest of mid-season biomass with two plants per plot available for end-of-season harvest data collection. The IR treatments followed the same protocol as the field study, with the exception of the last two applications. Due to large plant size and potential damage from movement, only seven IR applications were made to this study. To eliminate extraneous variables, 0-30-0 liquid foliar fertilizer (Growth Products, Ltd., White Plains, NY) was utilized for NP+FP treatments instead of 12-48-08. The 0-30-0 fertilizer utilized phosphoric acid as a source of P. The IR treatments were applied using a hand-held two-row boom at a spray volume of 93.5 L ha^{-1}. The spray nozzles used were Tee Jet® TXVS-12 Cone Jet nozzles.

Specific definitions were followed to assess the stage of growth for the IR treatment timings. Pinhead square and matchhead square occur when the size of squares on the cotton plant are equivalent to the size of a pinhead and matchhead, respectively.

First bloom was determined by the appearance of at least one white flower in the study. Early bloom was marked by the appearance of 5 to 6 white flowers per 100 plants. Mid-bloom period was defined by approximately 3 weeks of flowering (Ohlendorf et al., 1996). Peak bloom was determined by counting the number of white flowers per 100 plants. The point at which the white flower count is highest before declining is designated as peak bloom. Cutout occurs when the cotton reaches 5 average nodes above the first position white flower (Oosterhuis et al., 1996).

Data collection consisted of plant height, number of nodes, and NAWF measurements made at weekly intervals on each plant commencing prior to the first IR application and continuing for the duration of the study. Assessment of growth parameters included plant mapping and biomass partitioning at cutout, followed by post-season plant mapping and yield assessment. The plant mapping technique and program constructed for this project were based on an adaptation of the methods developed by Landivar (1993) and Jenkins and McCarty (1995). At cotton cutout, one plant from each plot was cut below the cotyledonary scars on the main stem. Dry weight data for each plant was recorded for stems, leaves, squares, and bolls as well as counts for number of squares and bolls. In addition, biomass partitioning data includes measurements for leaf area.

Fruiting distribution data and numerical counts were acquired through plant mapping at the end of the season. At harvest, the remaining two plants per plot were mapped to determine fruiting distribution and seedcotton yield.

Tissue analysis was conducted to determine the concentration of P in the leaf tissue. Due to financial considerations, tissue analysis was conducted on two of the three cultivars. It was determined that samples would be taken from the stacked-gene and conventional cultivars, ST4892BR and ST474, respectively. Due to limitations in the greenhouse, it was necessary to deviate from the sampling procedure utilized in the field study. The limited space of the greenhouse resulted in a small sample size from which leaf tissue was collected. In order to provide sufficient tissue weight for performing the analysis, all leaves were collected from the entire plant of each plot at 79 DAP. The plants used for leaf tissue analysis were those that were destroyed for collection of biomass partitioning data. Leaf petiole tissue was not included in the sampling. The timing for tissue sampling occurred approximately 2 days after the seventh IR treatment. The leaf samples were analyzed for nutrient content by the Texas A&M Soil, Water, and Forage Testing Laboratory located on the Texas A&M University campus in College Station, TX. Determination of nutrient concentration in leaf tissue was based on methods by Feagley et al. (1994). The results of this procedure allow the determination of P concentration comparisons between the respective IR treatments. Evidence from this analysis is important to ascertain if FP uptake was observed from the NP+FP and OP treatments.

Soil moisture levels were monitored daily by visual observation. Plants were protected from water stress through high-frequency irrigation with reverse osmosis water. A standard fertilizer regiment consistent with greenhouse practices for cotton was followed. Plant nutrient requirements were met through biweekly soil application of

maintenance fertilizer, followed by weekly treatments commencing after first flower. The maintenance fertilizers used were Peters Professional® water soluble fertilizer 20-20-20 (Scotts-Sierra Horticultural Products Company, Marysville, OH) and Scotts® STEM™ (soluble trace element mix) (Scotts-Sierra Horticultural Products Company, Marysville, OH). Insects were monitored by scouting and pressures minimized using broadcast NP insecticide applications, outside of the IR protocol, performed by the greenhouse technical staff (Appendix B). Greenhouse temperature data was recorded using a HOBO® Pro data logger (model: H08-032-08) (Onset Computer Corporation, Bourne, MA).

Statistical analysis was conducted on all appropriate data for this study. Some exploratory analysis of data was performed through the use of SPSS® (version 11.01) statistical software for computer systems running the Windows® platform (SPSS Inc., 1989-2001). In particular, the SPSS® software was used for developing profile plots, examination of homogeneity and normalcy of residuals, and statistical model development and comparison. The SAS® (version 8.1) statistical software was used for all final data analysis (SAS Institute, 1999-2000). Data was subjected to the Mixed Models Procedure with degrees of freedom estimated using the Satterthwaite approximation (Satterthwaite, 1946). Means were separated by the Tukey-Kramer procedure to determine statistical differences at α=0.05 significance level, unless otherwise noted. All graphical displays of data in this document were produced with Microsoft® Excel® 2002 (version 10.4302.4219-SP-2) spreadsheet software (Microsoft Corporation, 1985-2001).

RESULTS AND DISCUSSION

FIELD STUDY

Quantity of precipitation from planting until harvest for the two years differed by approximately 175.8 cm (231.89 cm in 2001 and 56.08 cm in 2002) (Fig. 1). Furthermore, the distribution of rainfall throughout the growing season between the two years was different. Several irrigations were required in 2001 from the period of peak bloom to first open boll due to a lack of precipitation. A large amount of precipitation at the end of the growing season in 2001 resulted in a delayed harvest. To minimize yield losses due to drought and insect pressures, all field plots were irrigated and NP broadcast insecticide applications were made as called for by scouting.

Data for the field study were combined over years as a result of the absence of statistical interaction between main effects and year. Additionally, no significant cultivar by IR treatment interactions were detected for the data presented in this document.

Yield

In general, yields from this field study reflected those produced in this area in previous years. Lint yields in 2002 were greater than those from 2001. Lint yield differed by 692 kg ha^{-1} between the two years with yield averaging 1015 and 1707 kg lint ha^{-1} in 2001 and 2002, respectively (Fig. 2). A planter problem in 2001 resulted in inconsistent seeding rates across the study. To homogenize the plant population, all plots were hand-thinned at the first true-leaf stage to a final population of 56,007 plants ha^{-1}. In 2002, planting was uneventful and subsequent stand counts were consistent in

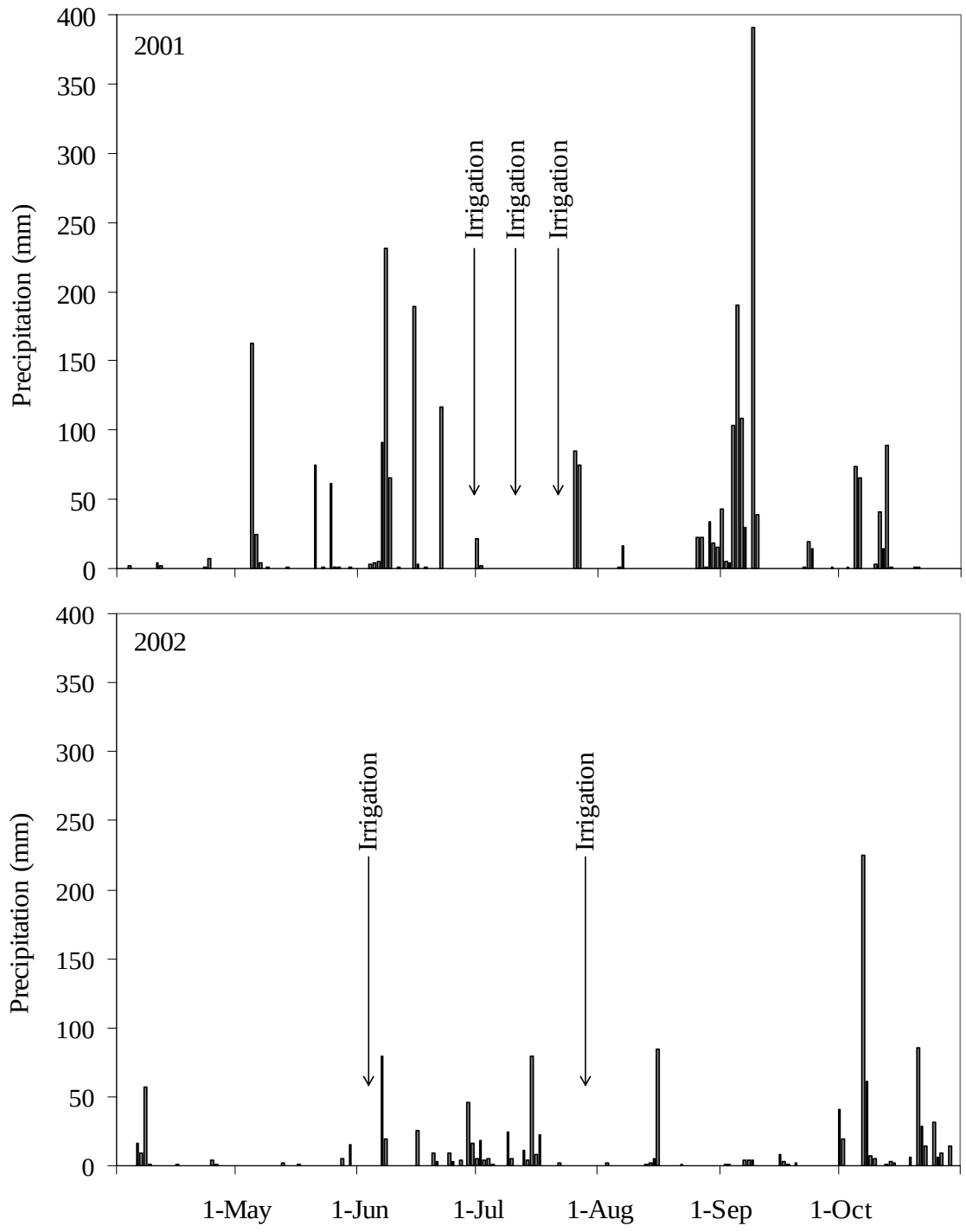

Fig. 1. Precipitation and irrigation from 1 Apr. to 31 Oct. for 2001 and 2002.

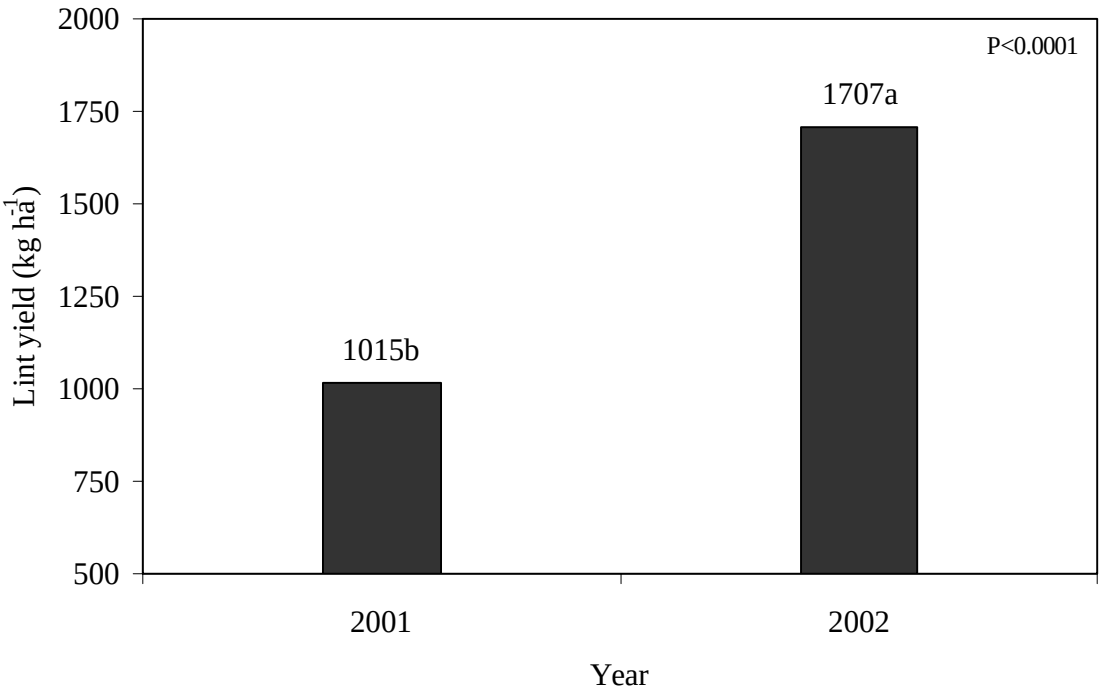

Fig. 2. Cotton lint yield for the 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

all plots resulting in a final population of 114,408 plants ha^{-1}.

Although 2002 presented an excellent year for growing cotton, the primary reason for the discrepancy in yield was likely the difference in plant population densities between the two years. A review of literature revealed inconsistent results regarding population density effects on cotton yield. Hernandez-Jasso and Guitierrez-Zamoran (2000) and Burris et al. (2001) reported significant lint yield reduction in cotton planted at populations as low as 50,000 and 32,277 plants ha^{-1}, respectively, compared to densities of 100,000 plants ha^{-1}. However, work by other authors reported no significant decrease in lint yield at population densities ranging from 19,700 to 37,050 plants ha^{-1} compared to densities reaching 251,000 plants ha^{-1} (Leffler, 1983; Boquet and Coco, 1996; Jones and Wells, 1998; Bednarz et al., 2000; Galadima et al., 2003). Cotton has remarkable ability to compensate for variable spacing (Kerby et al., 1996); previous research documents this characteristic. However, based on the studies reporting yield reduction from low populations, the low plant density in 2001 could be the potential cause for the yield discrepancy between the 2001 and 2002 field studies.

Cultivar was an important factor affecting yield. The yields for the three cultivars averaged across all IR treatments were 1233, 1320, and 1529 kg lint ha^{-1} for ST474, ST4793R, and ST4892BR, respectively (Fig. 3). ST4892BR produced greater lint yield than the other two cultivars. The yield for ST4793R was numerically greater than that of ST474, but was not statistically different. Yields for the IR treatments averaged across all cultivars were 1304, 1320, and 1458 kg lint ha^{-1}, for the OP, NP, and NP+FP treatments, respectively (Fig. 4). Though not significant at α=0.05, yields for

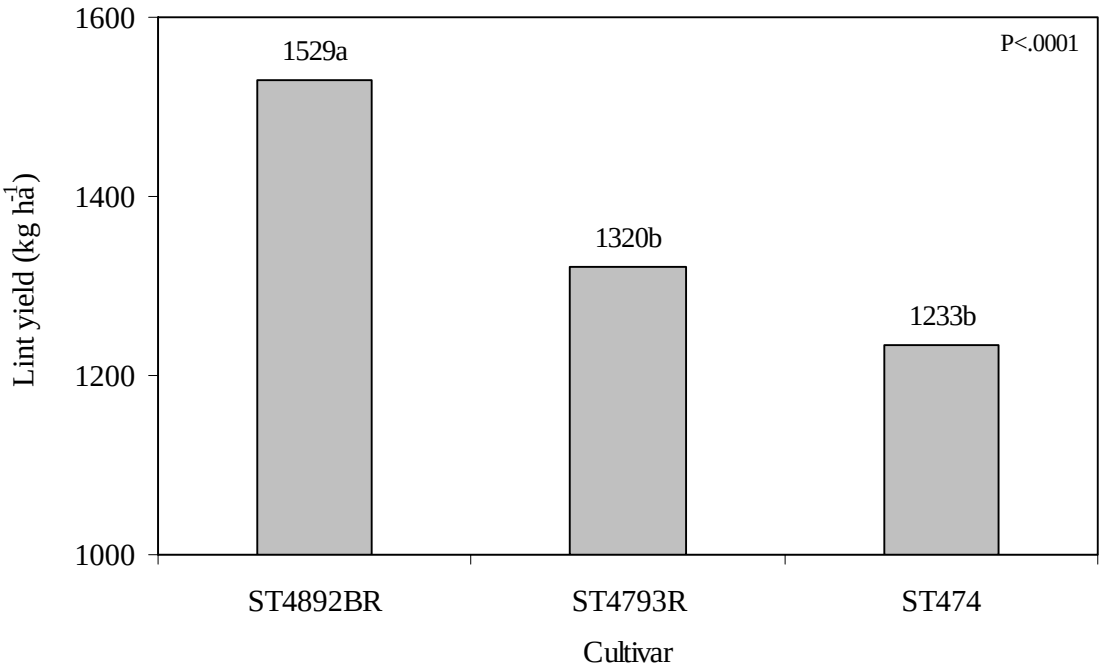

Fig. 3. Cotton lint yield combined over years as related to cultivar for the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

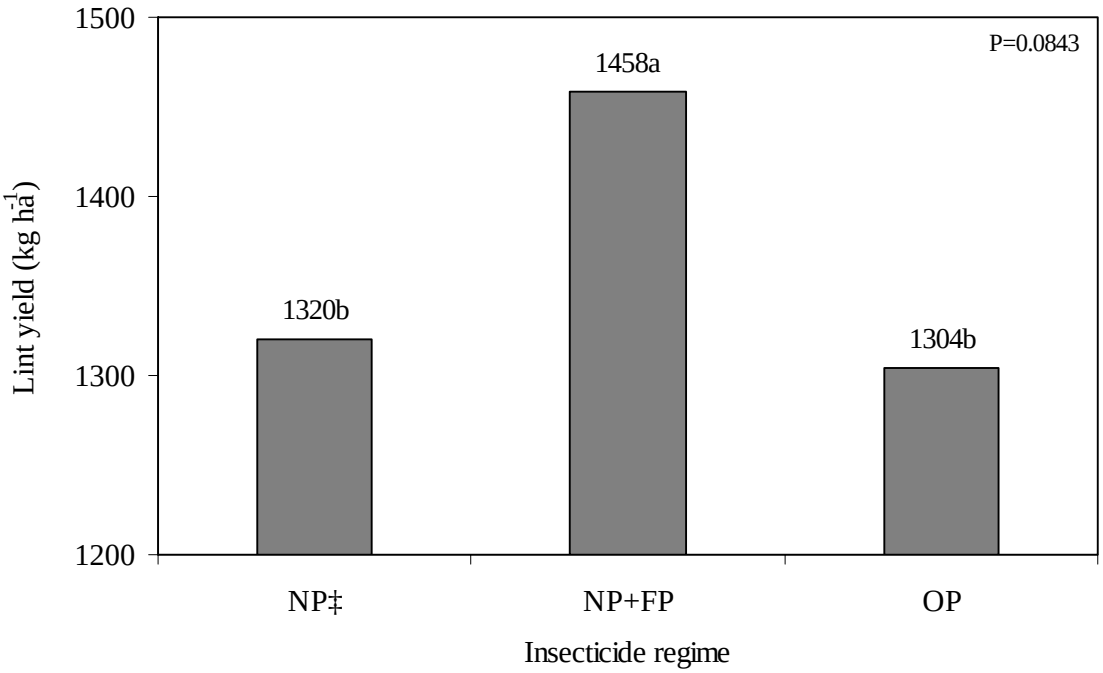

Fig. 4. Cotton lint yield combined over years as related to insecticide regime (IR) treatments for the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

the individual IR treatments exhibited a defined trend. If α=0.10 is permitted, a statistical yield difference is realized. Subsequently, it can be concluded that NP+FP produced a greater yield response (P=0.0843) than both the NP and OP treatments. Yields for the NP and OP treatments were not different. An interesting characteristic regarding IR yield differences is observed in the evaluation of seedcotton yield. Stronger statistical differences, based on the p-value, are evident between seedcotton yields of the respective IR treatments (Fig. 5). However, investigation of percent lint ginout revealed no significant differences between treatments (Fig. 6). The variability introduced by ginout differences between plots for the respective IR treatments may have increased the error associated with lint yield statistical analysis. This could potentially moderate statistical differences observed for the lint yields of IR treatments.

The yield results for the cultivars studied support the results of Moser et al. (2001) who reported that stacked-gene cultivars produced lint yields that were equal to or significantly greater than lint yields of their respective conventional parents, while Roundup Ready® cultivars produced lint yields that were similar to their conventional parent. The increased yield for ST4892BR is further supported by total boll numbers, mean boll weight, and fruiting distribution. Yield results regarding the IR treatments are substantiated through total boll numbers and fruiting distribution data. These data are presented in the end of season plant mapping section of this document.

Lint Quality Characteristics

Lint quality characteristics varied little between the 2001 and 2002 field studies for most of the lint classification parameters evaluated, with the exception of color grade

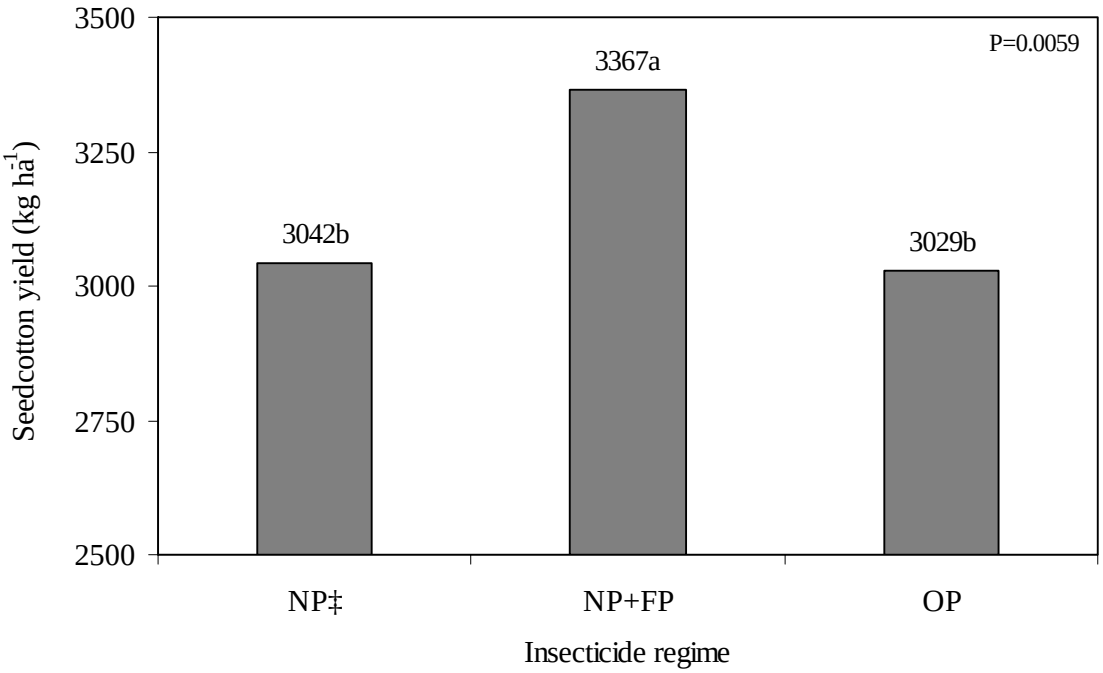

Fig. 5. Seedcotton yield combined over years as related to insecticide regime (IR) treatments for the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

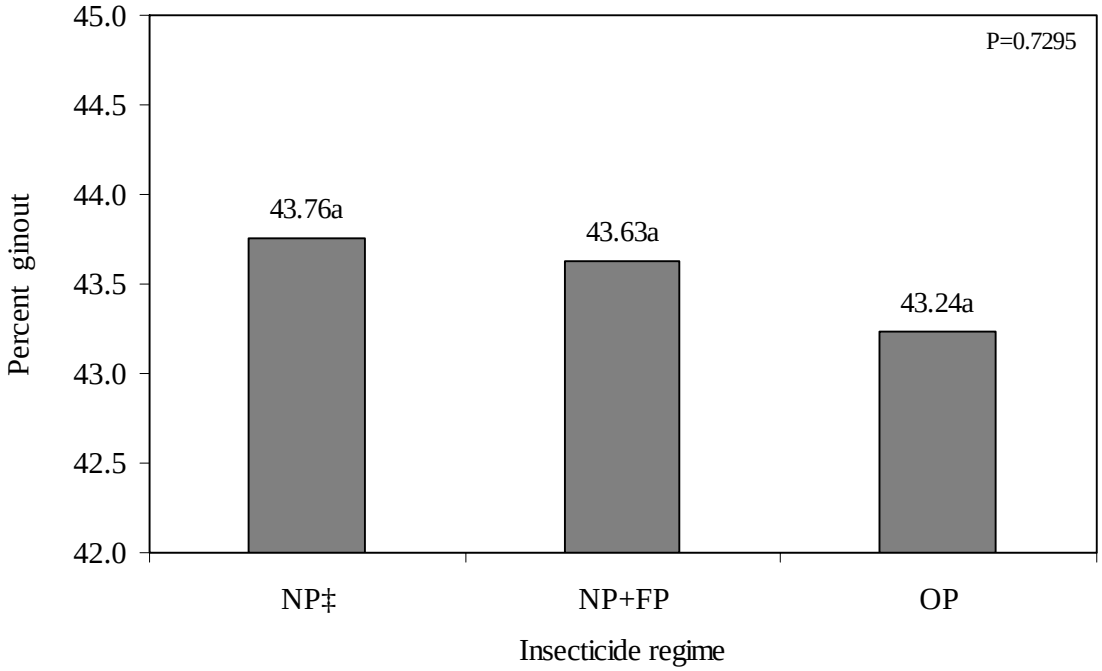

Fig. 6. Percent ginout of cotton combined over years as related to insecticide regime (IR) treatments for the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

and reflectance (Rd), and fiber strength (Table 3). With respect to the color characteristics of cotton, the values for Rd and yellowness in this study are within the normal ranges. Yellowness (+b) was numerically greater in 2001. Rd, sometimes referred to as grayness, was slightly greater in 2001. The various combinations of gray and yellow can be converted into a color grade by using the Nickerson-Hunter color diagram (USDA-AMS, 1993). Color grade was reduced in 2001. This could be attributed to the large amount of rainfall that subsequently delayed harvest in 2001 (Fig. 1). When mature cotton bolls first open, the lint is white and clean due to the highly reflective nature of cellulose and the lack of microbial degradation (Hake et al., 1996a). When lint is exposed to moisture, fungi start to multiply on the surface of the lint resulting in the deposit of dark colored microscopic fungal spores (Hake et al., 1996a). These spores cause the lint to become gray and dull, resulting in lower Rd reflectance values and reduced color grade. Though the Rd values in 2001 were deemed statistically greater than those from 2002, they only differed by approximately 2.5 points. This observation seems to go against the previous reasoning for the variance in color grade. However, it is the combination of +b and Rd values that result in color grade determination. That is why the rainfall remains the primary cause of reduced color grade in 2001. This conclusion is further supported by Williford et al. (1988) who found that rainfall can dramatically reduce color grade, especially if the cumulative amount exceeds 2 inches (50.8 mm) after the boll has opened.

Year also had an effect on fiber strength (Table 3). An increase of 2.66 g tex^{-1} was noted in 2002. Based on the 2002-2003 Commodity Credit Corporation (CCC) loan

Table 3. Effect of year on lint quality characteristics for 2001 and 2002 field studies.

Year	Leaf grade	Color grade	Fiber strength	Rd	+b
			— g/tex —		
2001	2.06 a†	64.37 b	27.65 b	57.79 a	8.58 a
2002	2.44 a	71.06 a	30.31 a	55.15 b	8.27 a

† Means within a column followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

rates for upland cotton, the increase in fiber strength in the 2002 study would have earned a 77 point kg^{-1} premium. Year did not affect leaf grade, micronaire, fiber length, or uniformity.

Lint quality characteristics between the three cultivars were not different for most parameters. Fiber length is the only parameter in which statistical differences between cultivars were noted. ST474 produced longer fibers than ST4793R, measuring 2.76 and 2.73 cm, respectively (Table 4). ST4892BR fiber length was not different from either ST474 or that of ST4793R. Based on CCC loan rate criteria for these length measurements, ST474 could have received a lesser discount than ST4793R. Though ST4892BR did not vary statistically from the other two cultivars, its numerically higher length value could have also placed it in the same discount category as ST474.

The insecticide application regime did not affect lint quality characteristics (Table 5). All fiber quality parameters for cultivar and IR effects were within normal lint classification ranges and reflected expected values of cotton produced locally. Lint quality characteristics were not significantly affected by cultivar or IR treatments.

Leaf Tissue Nutrient Analysis

Quantifying leaf tissue nutrient content is important for explaining potential IR treatment effects on plant growth, yield, and fiber quality characteristics. The tissue nutrient analyses were performed to answer specific questions regarding the main effects of this study: 1) Are plants acquiring P from OP insecticides?; 2) Were foliar P applications providing P at an equivalent rate as OP insecticides?; and 3) Does cultivar technology type have an influence on leaf P concentration?

Table 4. Cultivar effects on lint quality characteristics combined over years for the field study.

Cultivar	Micronaire	Fiber length	Fiber strength	Uniformity	Leaf grade
		— cm —	— g/tex —		
ST4892BR	5.29 a†	2.75 ab	29.09 a	84.01 a	2.41 a
ST4793R	5.18 a	2.73 b	29.07 a	83.86 a	2.10 a
ST474	5.07 a	2.76 a	28.77 a	83.67 a	2.25 a

† Means within a column followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

Table 5. Insecticide regime (IR) effects on lint quality characteristics combined over years for the field study.

IR	Micronaire	Fiber length	Fiber strength	Uniformity	Leaf grade
		— cm —	— g/tex —		
NP‡	5.24 a†	2.76 a	29.00 a	83.97 a	2.32 a
NP+FP	5.16 a	2.74 a	29.03 a	83.71 a	2.15 a
OP	5.14 a	2.75 a	28.90 a	83.85 a	2.32 a

† Means within a column followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

‡ The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Analytical results for leaf tissue nutrient concentrations of the IR treatments revealed the concentrations of P in the tissue for NP, NP+FP, and OP treatments were 2.49, 2.94, and 3.12 g P kg^{-1}, respectively (Fig. 7). The tissue samples were acquired after eight IR applications; therefore, the P levels from tissue nutrient analysis reflect a cumulative applied amount of 0.3743 kg P ha^{-1} (Table 6). Total kg P ha^{-1} applied from nine applications of the IR regime (NP+FP and OP treatments) amounted to 0.4675 kg P ha^{-1}. The cumulative amount of P applied in nine IR applications for this study is somewhat less than the amounts reported in other foliar nutrient studies. Work by Bednarz et al. (1998) and Bednarz et al. (1999) failed to show a significant yield response in cotton to 1.12 kg P ha^{-1} applied from three separate foliar applications of 0.373 kg P ha^{-1}. Conversely, Lancaster and Savatli (1965) reported that, in field experiments, 1.12 kg ha^{-1} phosphorus applied to the leaves gave a higher increase in yield than when applied to the soil. However, their results clearly indicated that foliar feeding of phosphorus during periods of high nutrient needs, as may be engendered by development of a heavy boll load, is not necessary for obtaining maximum yield. They further contend that the roots of the cotton plant have the capacity to absorb all the phosphorus needed by the above-ground portion of the plant during stress periods and that levels of soil phosphorus adequate to supply these needs may occur naturally or as a result of proper fertilization practices.

In the 2001 and 2002 field studies, plants acquired P from OP insecticides. Applications of OP insecticides increased leaf P concentration by 0.63 g P kg^{-1} ($P=0.004$) compared to NP insecticides. Furthermore, NP+FP increased leaf P

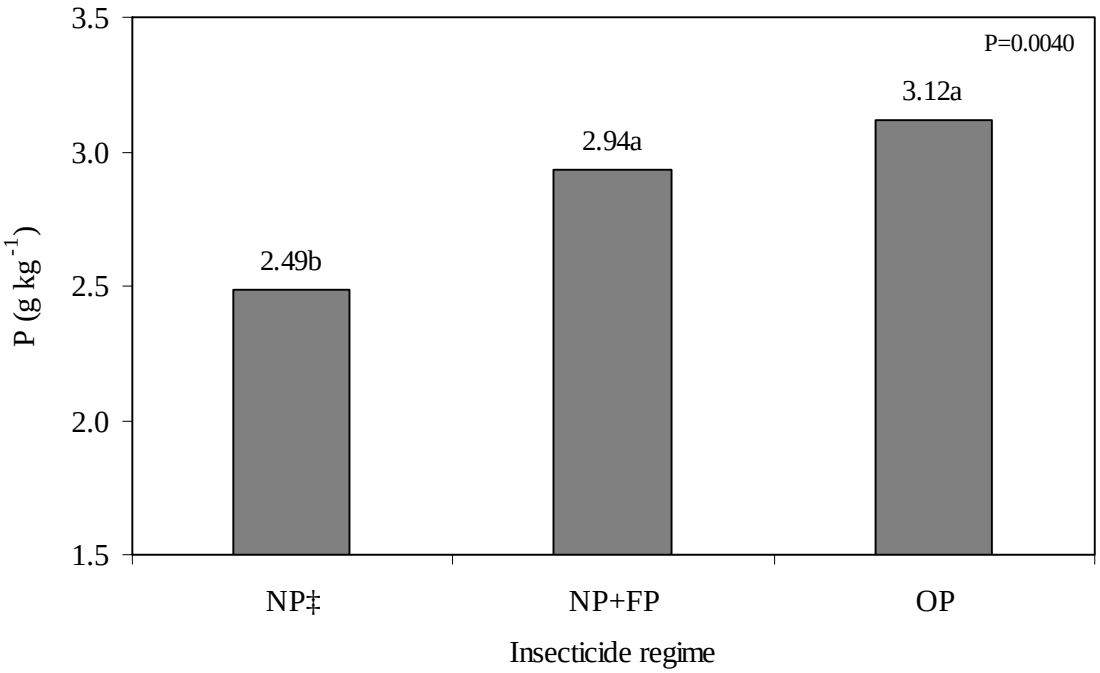

Fig. 7. Phosphorus (P) concentration in leaf tissue combined over years for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Table 6. Amount of phosphorus (P) applied through individual NP+FP foliar treatments for nine insecticide regime (IR) treatment applications in the field study.

IR Application Number	kg 12-48-08 ha^{-1}	kg P_2O_5 ha^{-1}	kg P ha^{-1}
1	0.1307	0.0627	0.0274
2	0.1307	0.0627	0.0274
3	0.1307	0.0627	0.0274
4	0.1307	0.0627	0.0274
5	0.2626	0.1260	0.0550
6	0.3335	0.1601	0.0699
7	0.3335	0.1601	0.0699
8	0.3335	0.1601	0.0699
9	0.4446	0.2134	0.0932
Total	2.2302	1.0705	0.4675

concentration 0.45 g P kg^{-1} compared to the NP treatment. These results are consistent with Bednarz et al. (1999), who reported that foliar P applications increased leaf P concentration 0.80 g P kg^{-1} over the untreated check.

Increases in P from the NP+FP and OP treatments were consistent. A difference in P concentration of 0.18 g P kg^{-1} exists between the treatments and was determined insignificant through statistical analysis. These results indicate that the NP+FP treatments provided P at an equivalent rate as the OP treatments.

The results from the P concentration of leaf tissue samples reveal an interesting phenomenon with this study. Lint yields for the IR treatments showed the NP+FP yields were significantly increased over NP treatments. Since the increase in P concentrations for NP+FP and OP were similar and significantly greater than the NP treatment, it was expected that the OP yields would also reflect the increase in P concentration. However, this was not the case. OP applications had little effect on lint yield. Two variables concerning the foliar fertilizer of choice could not be controlled in the field experiment. Problems obtaining a fertilizer containing only phosphorus for foliar IR use resulted in selection of the 12-48-08 fertilizer for the NP+FP treatment. The amount of nitrogen (N) and potassium (K) in this fertilizer were thought to be insignificant when considering the rates applied; however, in an effort to explain this discrepancy, leaf K concentrations were evaluated. A total of 0.0741 kg K ha^{-1} was applied through nine NP+FP applications (Table 7). Approximately 0.0593 kg K ha^{-1} was applied from the eight IR applications at the time the leaf tissue was sampled. Although slight numerical differences are apparent in leaf K concentrations between treatments, no statistical

Table 7. Amount of potassium (K) applied through individual NP+FP foliar treatments for nine insecticide regime (IR) treatment applications in the field study.

IR Application Number	kg 12-48-08 ha^{-1}	kg K_2O ha^{-1}	kg K ha^{-1}
1	0.1307	0.0105	0.0043
2	0.1307	0.0105	0.0043
3	0.1307	0.0105	0.0043
4	0.1307	0.0105	0.0043
5	0.2626	0.0210	0.0087
6	0.3335	0.0267	0.0111
7	0.3335	0.0267	0.0111
8	0.3335	0.0267	0.0111
9	0.4446	0.0356	0.0148
Total	2.2302	0.1784	0.0741

differences exist (Fig. 8). The NP, NP+FP, and OP treatments had 11.38, 11.82, and 12.20 g K kg^{-1} leaf tissue, respectively. Based on these results, it is improbable that the additional K applied in the NP+FP treatments had an effect on yield. Due to limited financial resources, analysis of leaf N concentration was not performed. A total of 0.2677 kg N ha^{-1} was applied through nine NP+FP applications (Table 8). Although foliar feeding of nutrients can potentially alleviate nutrient stress during peak demand periods, it is unlikely that this small amount of foliar applied N could have affected yield to the extent observed. McConnell et al. (1998) conducted a study involving soil-applied and foliar-applied nitrogen. Treatments with an additional 33.6 kg N ha^{-1} applied to foliage produced a yield response. However, yield responses to foliar N tended to differ between years and between irrigated and dry land cotton production conditions. They found that, generally, foliar-applied N applications resulted in increased yield when soil-applied N was less than optimal. The findings of McConnell et al. (1998) are important to evaluating the likelihood that additional N applied in this study could explain the yield increase for the NP+FP treatment. McConnell et al. (1998) found variable yield results when applying 126 times the amount of N that was applied in our study. Therefore, it is reasonable to conclude that the small amount of N applied through the use of 12-48-08 fertilizer did not influence the yields of the NP+FP treatment.

The leaf P concentration between the two cultivars sampled was similar. Phosphorus concentrations in the leaf tissue for ST4892BR and ST474 were 2.82 and 2.88 g P kg^{-1}, respectively (Fig. 9), which indicates that technology type does not influence leaf P concentrations in the cultivars studied.

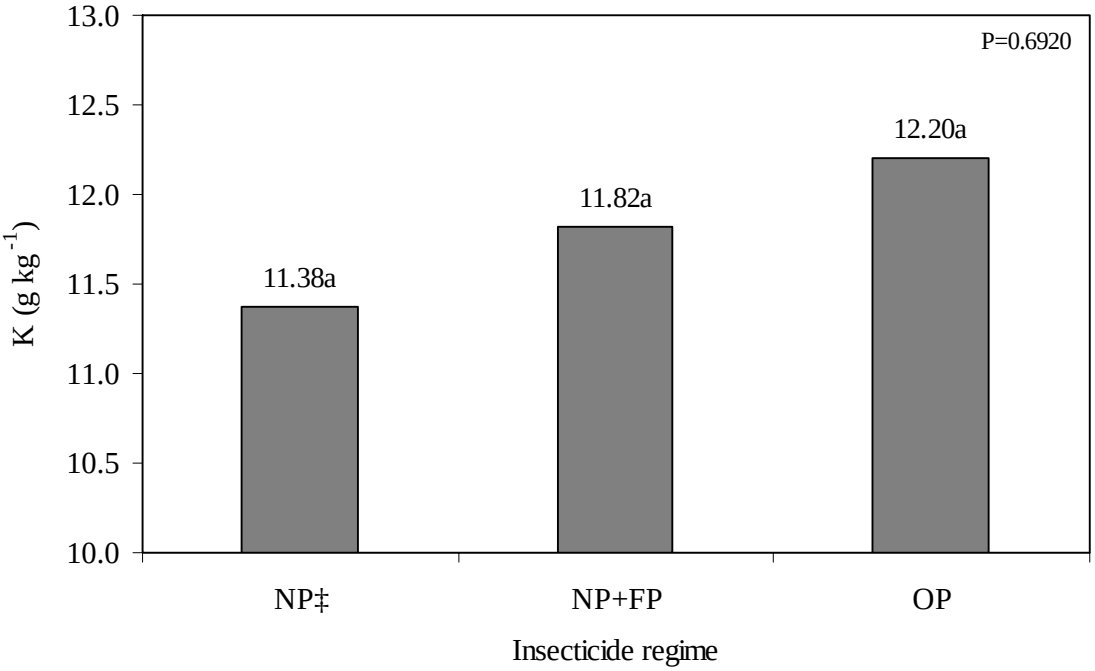

Fig. 8. Potassium (K) concentration in leaf tissue combined over years for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Table 8. Amount of nitrogen (N) applied through individual NP+FP foliar treatments for nine insecticide regime (IR) treatment applications in the field study.

IR Application Number	kg 12-48-08 ha^{-1}	kg N ha^{-1}
1	0.1307	0.0157
2	0.1307	0.0157
3	0.1307	0.0157
4	0.1307	0.0157
5	0.2626	0.0315
6	0.3335	0.0400
7	0.3335	0.0400
8	0.3335	0.0400
9	0.4446	0.0534
Total	2.2302	0.2677

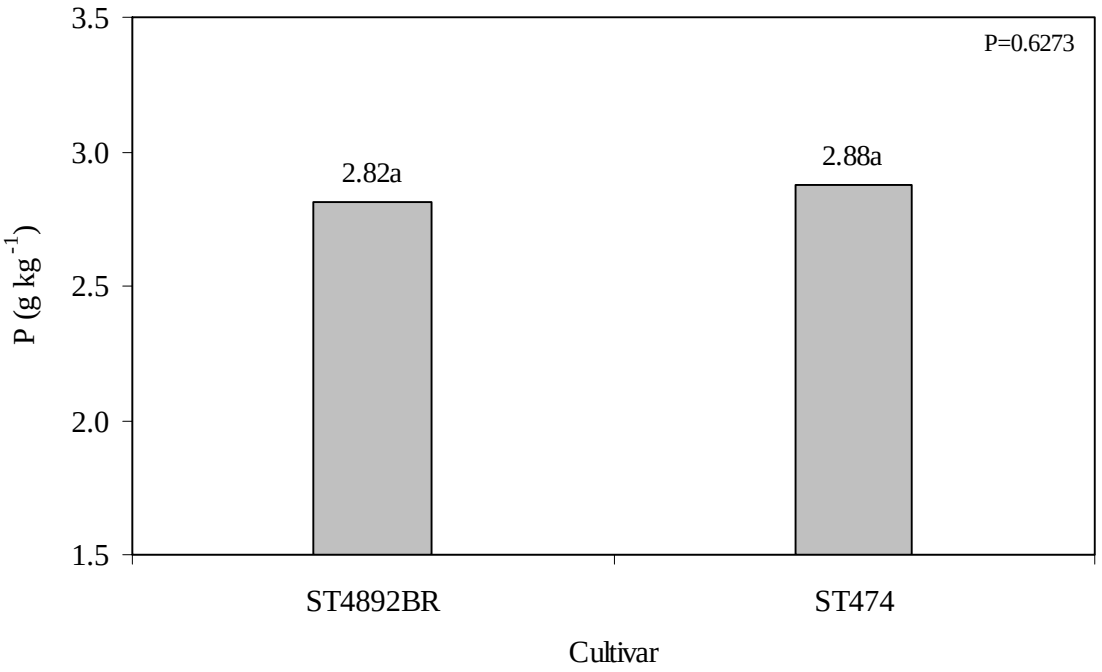

Fig. 9. Phosphorus (P) concentration in leaf tissue combined over years for two cotton cultivars in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure.

Plant Growth Parameters

Several of the parameters in this study were assessed on periodic intervals during the growing season. Plant height, nodes, internode length, and NAWF were monitored to compare growth trends and to determine if differences existed at specific stages in the season. Analysis of covariance (ANCOVA) was used to compare the slopes of the main effects and establish whether the slopes were different. The analysis of covariance procedure is used as a method of comparing a series of regression models – one for each of the levels of a factor or combinations of levels of factors being studied (Milliken and Johnson, 2002).

The rate at which plant height increased for the three cultivars was similar from mid-bloom (70 DAP) to cutout (99 DAP) (Fig. 10). ST4793R had a slightly greater rate of height increase than the other two cultivars; however, all slopes were statistically equal (P=0.1252). Among all individual sampling dates, ST4792BR had greater height than the conventional cultivar. At mid-bloom, ST4892BR was taller (P=0.0608) than ST4793R and ST474 with plant heights measuring 76.6, 72.2, and 72.6 cm, respectively (Fig. 11). ST4793R and ST474 did not differ in height at this sampling point. As illustrated previously (Fig. 10), a slightly greater slope for ST4793R results in a smaller height contrast between it and the other two cultivars at peak bloom and cutout (Fig. 11).

Application of IR treatments had little effect on plant height. Height trends over the reported period of time revealed no differences in rate of increase (Fig. 12).

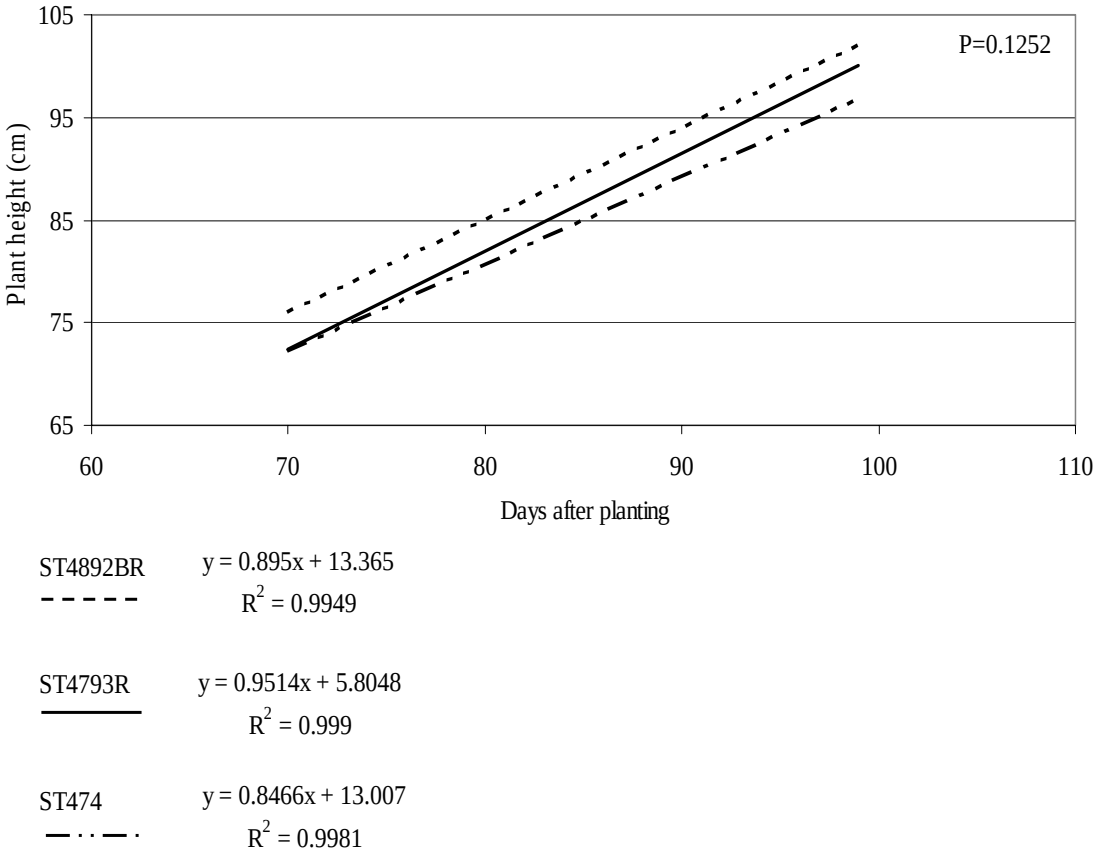

Fig. 10. Height trends combined over years for three cotton cultivars from 70 to 100 days after planting in the field study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines are statistically different at $P<0.05$ according to the analysis of covariance procedure.

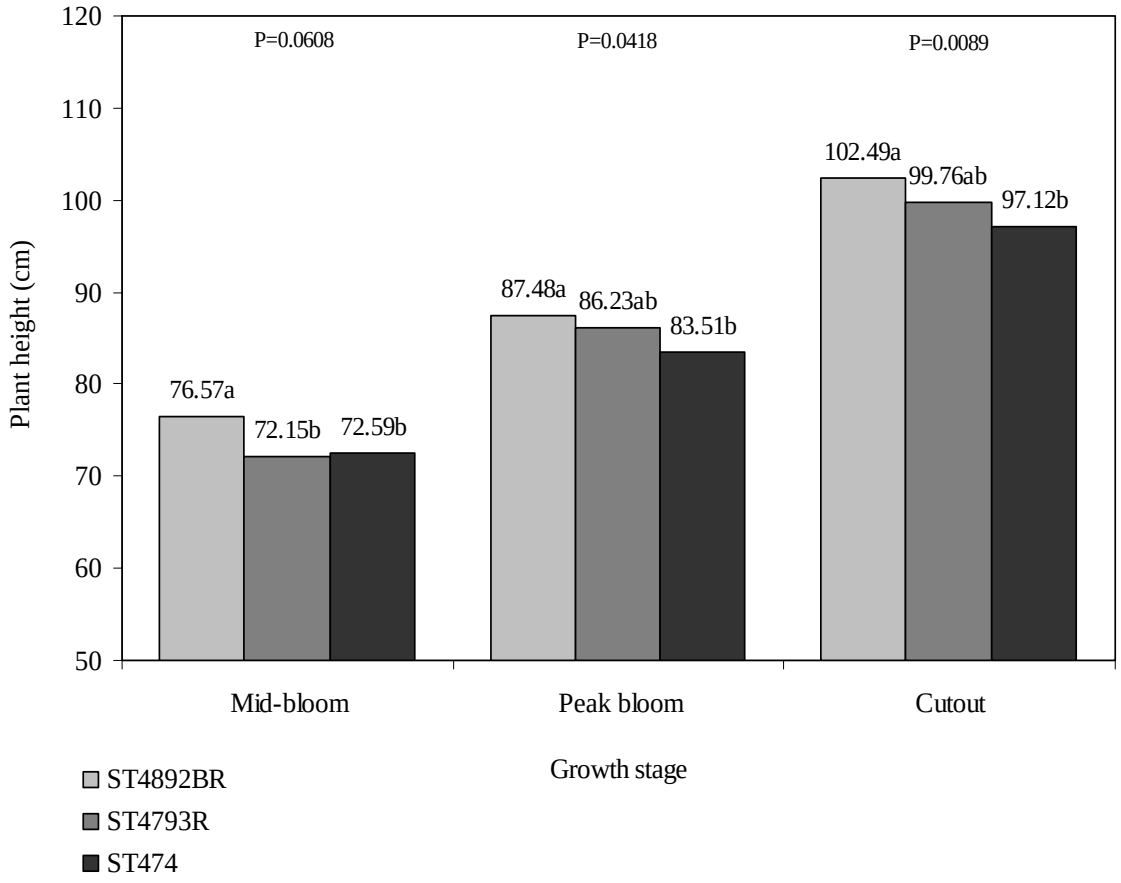

Fig. 11. Plant height combined over years for three cotton cultivars at mid-bloom, peak bloom, and cutout in the field study. Means followed by the same letter are not statistically different at P<0.10 (mid-bloom), and P<0.05 (peak bloom and cutout) according to the Tukey-Kramer procedure.

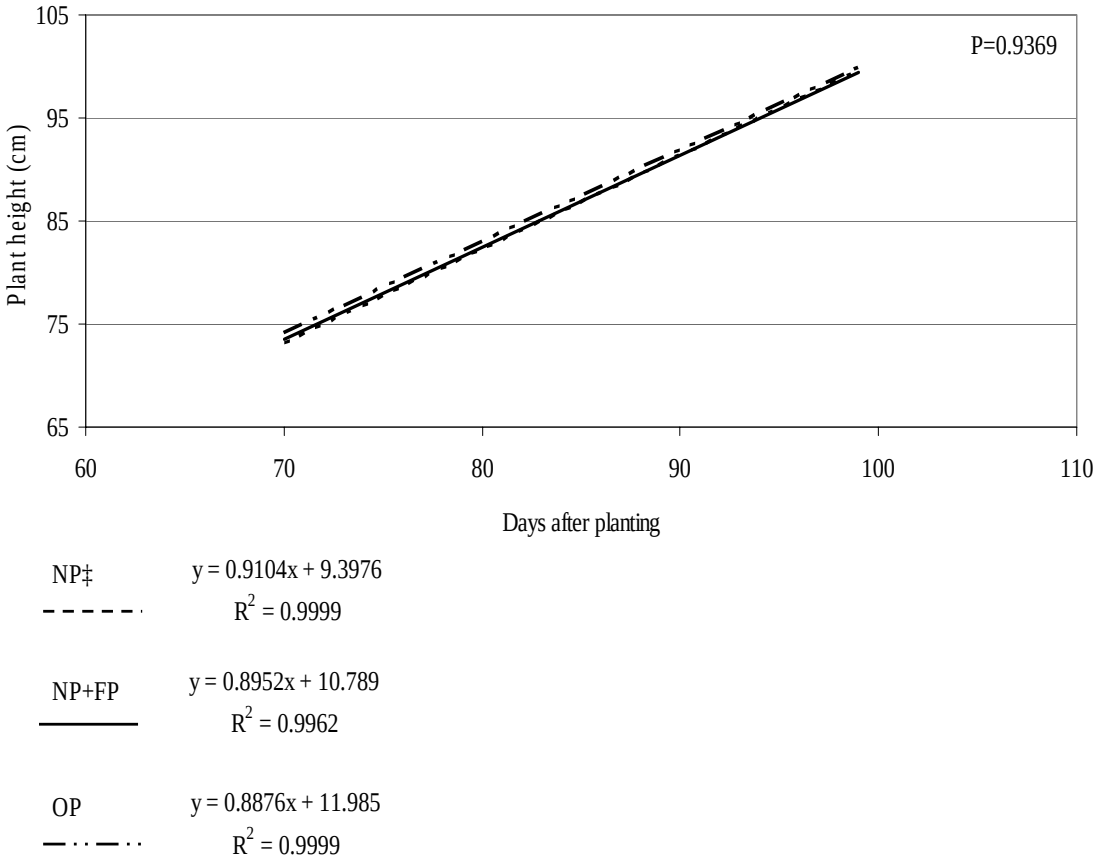

Fig. 12. Height trends combined over years for insecticide regime (IR) treatments from 70 to 100 days after planting in the field study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines are statistically different at $P<0.05$ according to the analysis of covariance procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Furthermore, lack of height differences for IR main effects at individual sampling dates suggests no apparent influence of IR applications on plant height.

The total number of nodes per plant varied little during the season for the three cultivars (Fig 13). At mid-bloom, ST474 had approximately 0.5 more nodes (P=0.0543) than ST4793R. However, this difference was mitigated as the season continued. No differences were detected at peak bloom and cutout.

Similarly, IR treatments had no effect on total node numbers. At mid-bloom, approximately 17 nodes per plant were recorded for each of the IR treatments (Fig. 14). The same trend continued for the duration of the season with approximately 19.5 and 20.5 recorded nodes at peak bloom and cutout, respectively.

Average internode length can also be utilized to evaluate crop vegetative growth rate. This parameter takes into consideration the direct correlation between plant height and internode length. Average internode length is determined by dividing plant height by the total number of nodes. A comparatively large value is indicative of a more robust plant and possibly fewer potential fruiting branches. Comparing the slope of the regression lines for average internode length over time can provide insight about the behavior of the crop throughout the growing season.

At mid-bloom, ST4892BR had a longer internode length than both ST4793R and ST474 with values of 4.5, 4.3, and 4.2 cm, respectively (Fig. 15). ST4793R and ST474 had similar average internode lengths. The measurements at peak bloom showed similar trends with the exception of ST4793R; the contrast between ST4793R and ST4892BR dissipated, resulting in no statistical difference. Furthermore, there was not enough of

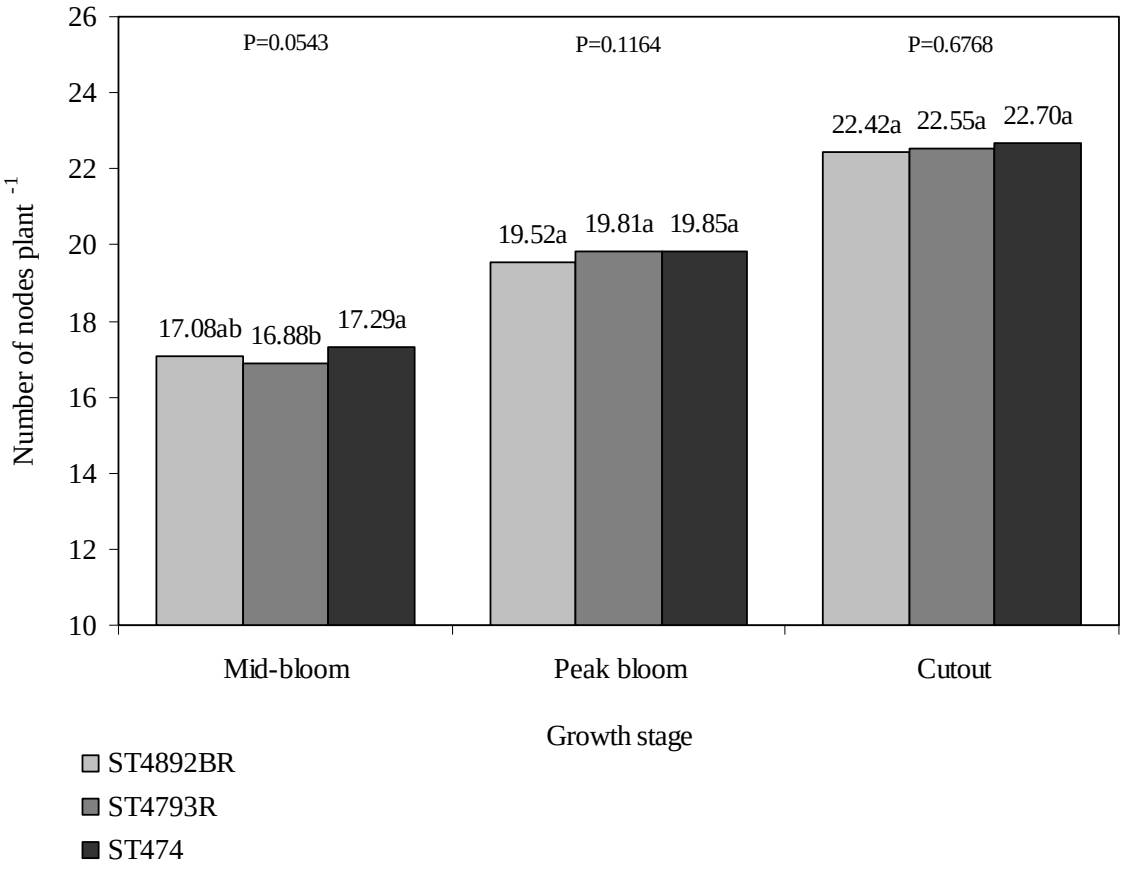

Fig. 13. Number of main-stem nodes combined over years for three cotton cultivars at mid-bloom, peak bloom, and cutout in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

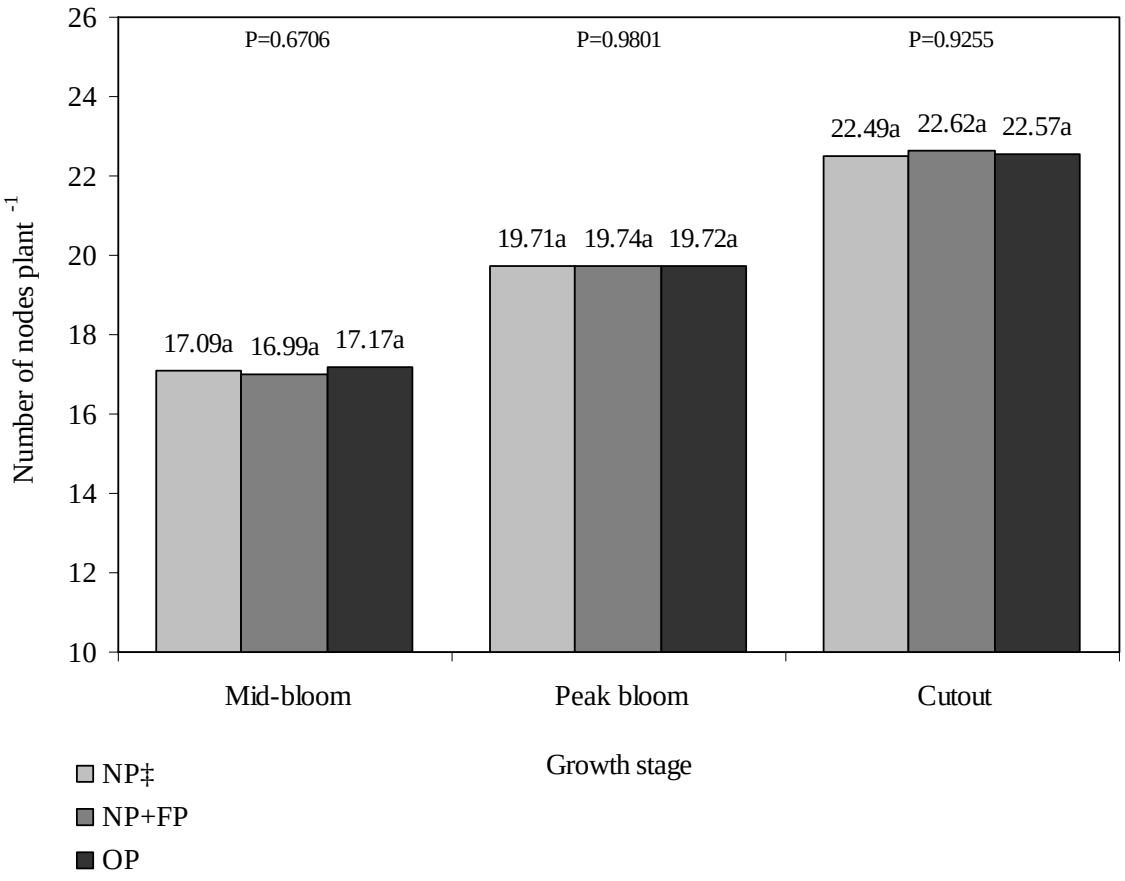

Fig. 14. Number of main-stem nodes combined over years for insecticide regime (IR) treatments at mid-bloom, peak bloom, and cutout in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

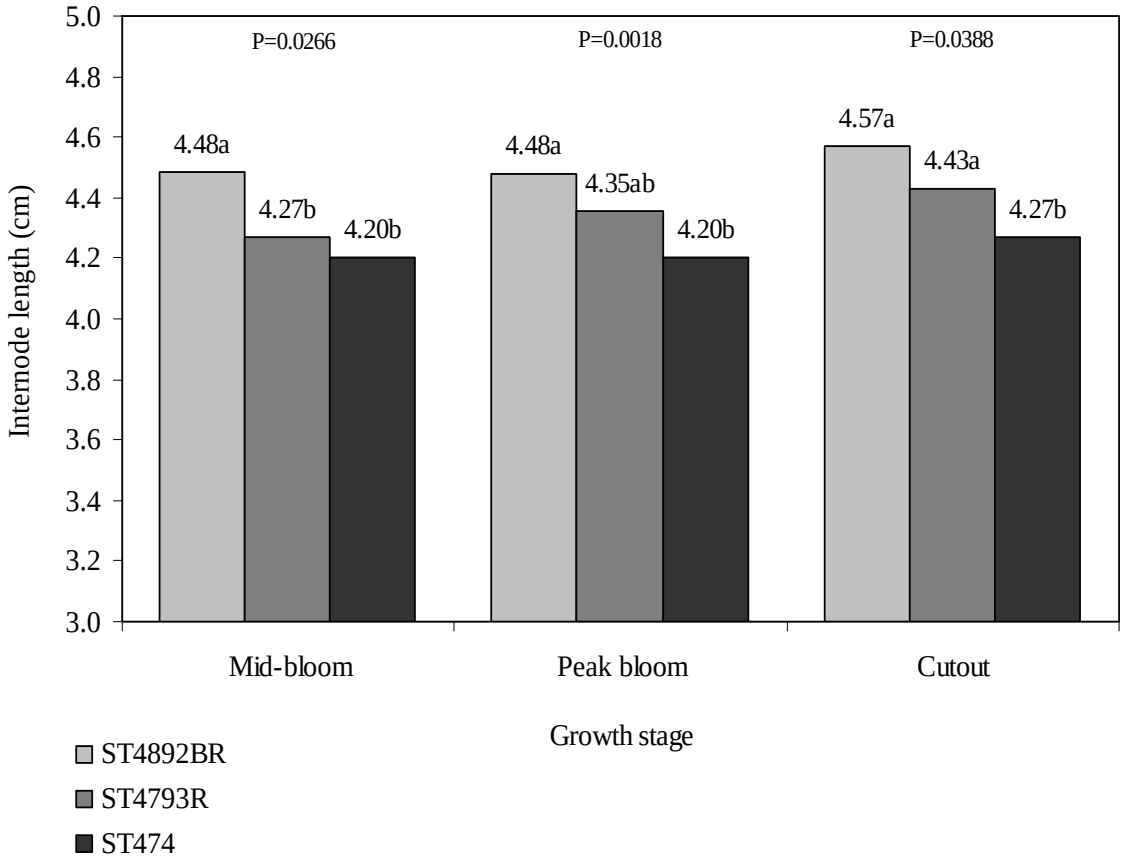

Fig. 15. Average internode length combined over years for three cultivars at mid-bloom, peak bloom, and cutout in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure.

an increase in average internode length compared to that of ST474 to result in a difference, either. At peak bloom, ST4892BR and ST474 internode length did not change from the value recorded at mid-bloom. The trend reflected in the previous two sampling periods was mirrored at cutout. ST474 exhibited the smallest internode length, while ST4793R and ST4892BR had the largest with lengths of 4.3, 4.4, and 4.6 cm, respectively. The reduced internode length is a result of ST474 having a decreased height while maintaining the same number of nodes, which suggests a potentially greater shift in carbohydrate translocation from vegetative to reproductive growth compared to the transgenic cultivars. Evaluating the trends across all three sampling periods further illustrates the previous remarks. The slopes for the three cultivars across all dates were statistically equal (P=0.4076) (Fig. 16). However, a slightly greater slope for ST4793R (Fig. 16) explains the changes in mean groupings throughout the sampling period (Fig 15). Overall, the growth rates of the three cultivars, as indicated by average internode length regression model comparison, were similar from mid-bloom to cutout.

Application of IR treatments had little effect on average internode length. The values for NP+FP fluctuated slightly throughout the sampling period (Fig. 17). None of the treatments exhibited significantly different mean internode length values at any sampling date, which is confirmed by the comparing slopes across the sampling period. Growth trends were similar for all three treatments (Fig. 18).

Stage of growth for any crop is an important factor on which management decisions are based. Periodic monitoring of this parameter can provide insight about development and maturation, in terms of the progression towards physiological cutout,

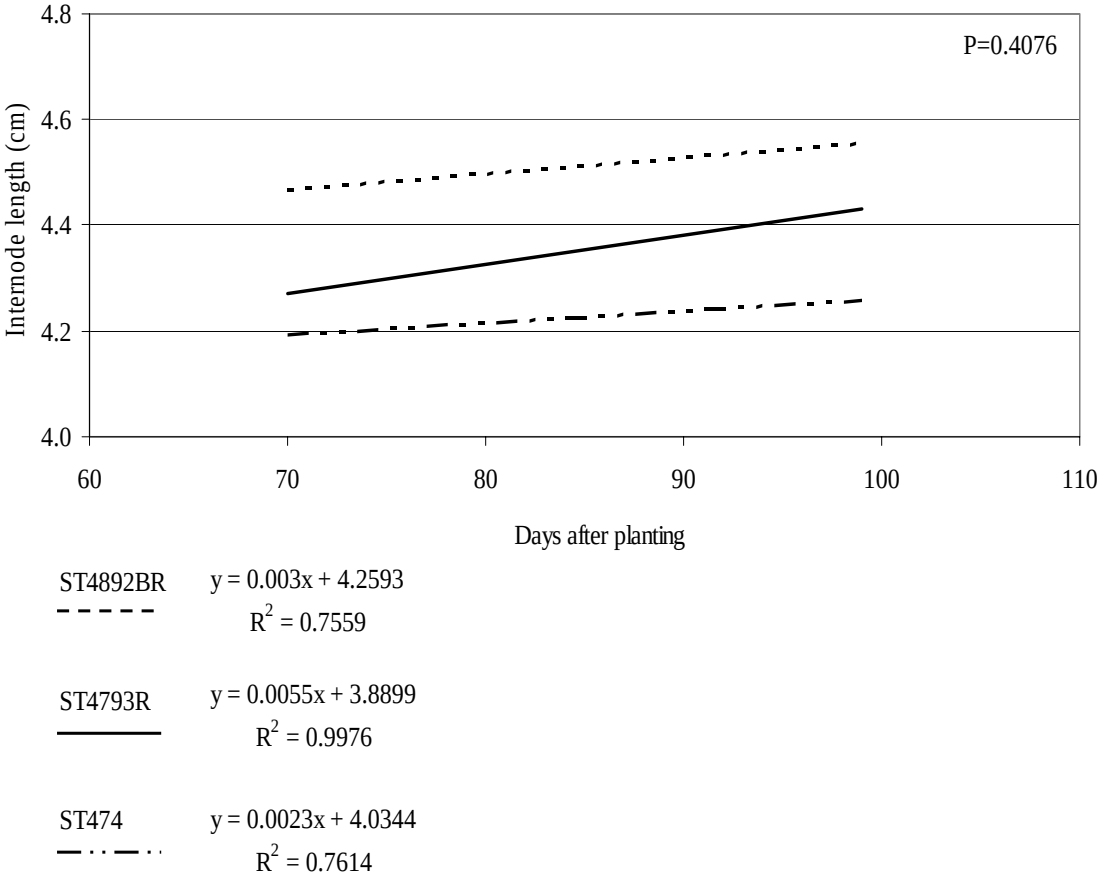

Fig. 16. Average internode length trends combined over years for three cotton cultivars from 70 to 100 days after planting in the field study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines are statistically different at $P<0.05$ according to the analysis of covariance procedure.

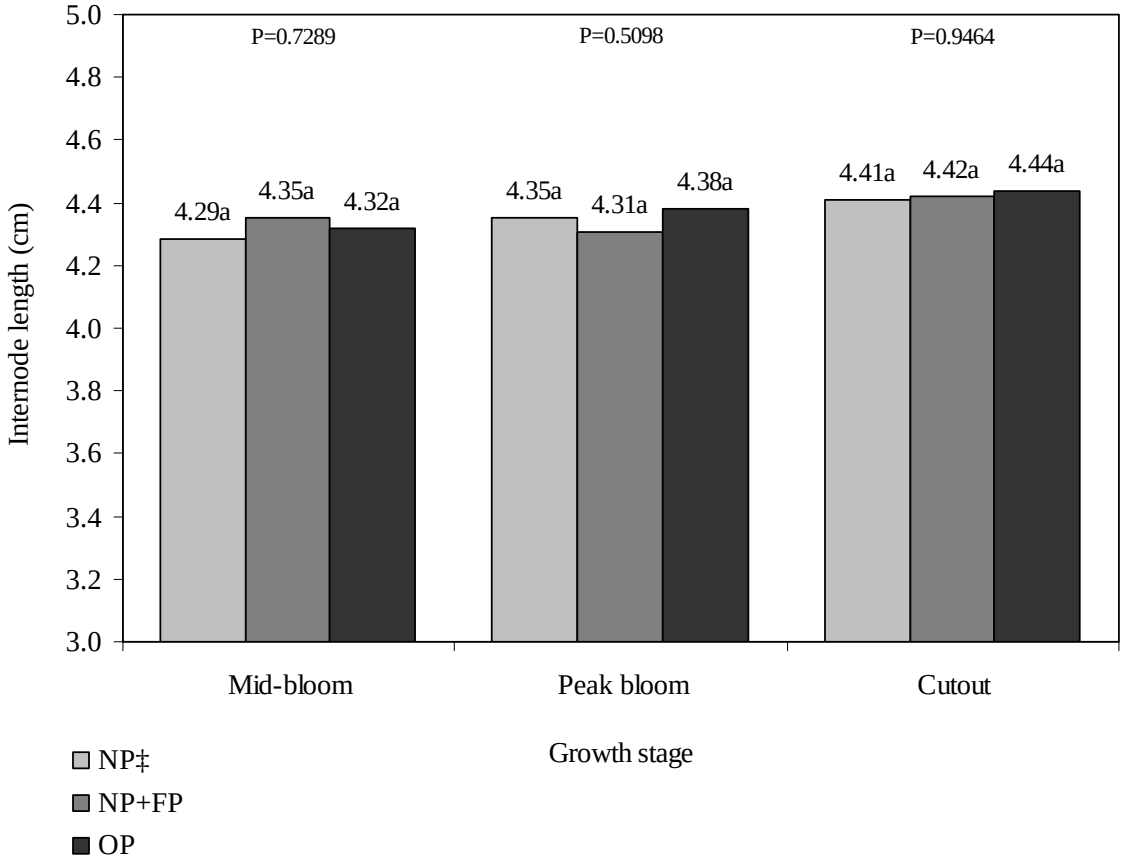

Fig. 17. Average internode lengths combined over years for insecticide regime (IR) treatments at mid-bloom, peak bloom, and cotton cutout in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

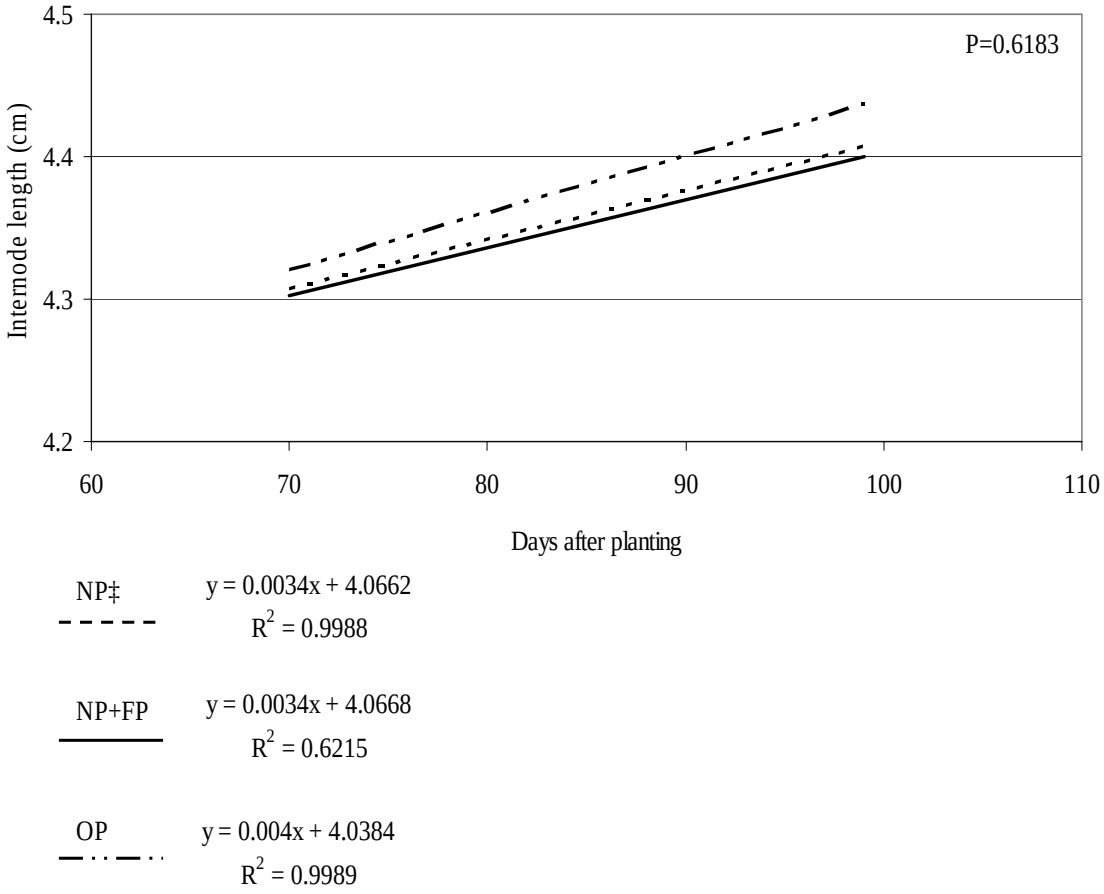

Fig. 18. Average internode length trends combined over years for insecticide regime (IR) treatments from 70 to 100 days after planting in the field study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines are statistically different at $P<0.05$ according to the analysis of covariance procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

for cotton (Bourland et al, 1992). Cutout is defined as the point during the growing season at which the number of nodes above white flower (NAWF) averages five (Oosterhuis et al., 1996). At this stage of crop maturity, the terminal growth slows to the point that the first position white flower is at the fifth node below the most recently unfurled leaf (Andrews et al., 2001). In addition, a diameter criterion of at least 2.5 cm must be met for consideration of the young leaf in this measurement. The physiology underlying the occurrence of cutout in cotton is related to carbohydrate demand. Cutout occurs when boll load consumes all available carbohydrates produced by the leaves (Kerby and Hake, 1996). The white blooms present at cutout are considered the last boll population that will effectively contribute to yield. Furthermore, typical management practices will cease additional insecticide applications targeted at protecting these developing bolls when the accumulation of heat units after cutout reaches 350 to 400 degree day units (Andrews et al., 2001). Degree day units (DD60s) are calculated by averaging the daily maximum and minimum temperatures and subtracting a baseline temperature for cotton of 60° C (Mauney, 1986).

Regression lines for NAWF versus days after planting (DAP) were constructed to examine differences in the progression towards cutout between years, cultivars, and IR. There is evidence that the progression rate for cutout was greater for the 2001 crop (Fig. 19). The slopes for 2001 and 2002 are not equal ($P<0.0001$). This analysis indicates that the 2001 study was a slightly faster maturing crop. Because temperature and moisture can have a dramatic impact on rate of maturity, differences in DD60s and

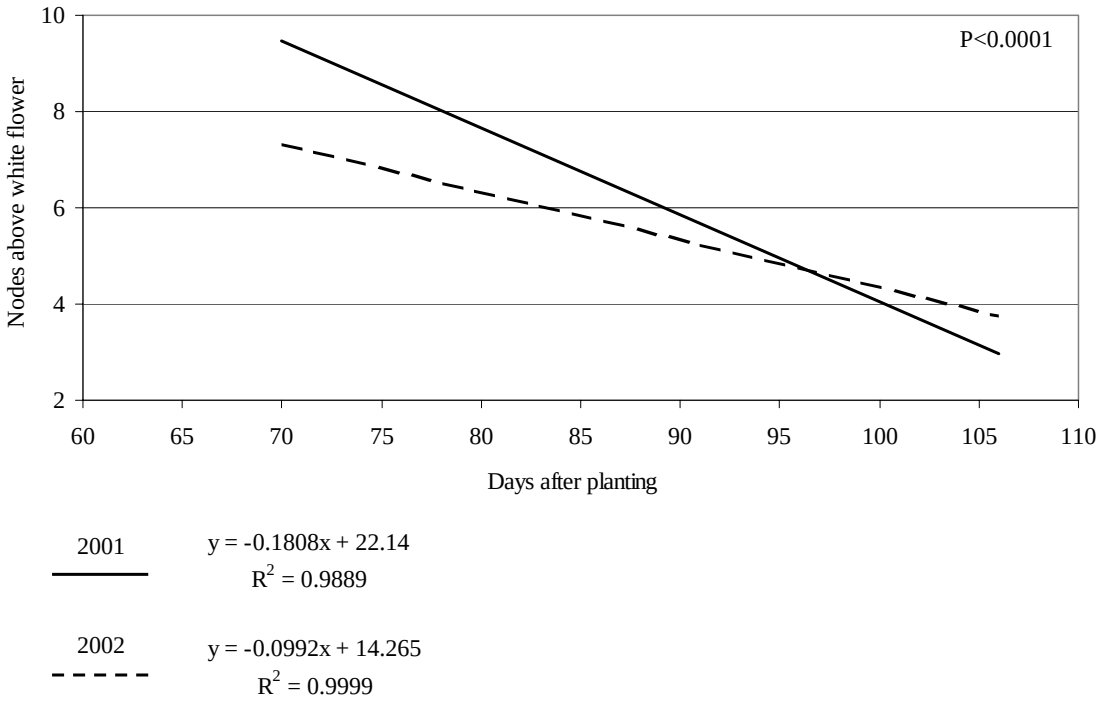

Fig. 19. Average nodes above first position white flower (NAWF) trends from 70 to 105 days after planting for the 2001 and 2002 field studies. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines are statistically different at $P<0.05$ according to the analysis of covariance procedure.

precipitation amounts between 2001 and 2002 were investigated as a possible explanation for this anomaly.

Cumulative precipitation for both years differed dramatically. A greater amount of precipitation was received in 2001 compared to 2002 (Fig. 20). At 100 DAP, the cumulative precipitation in 2001 was 2.5 times that recorded for 2002. The precipitation data showed that a large proportion of the total cumulative precipitation at 100 DAP for 2001 was received prior to 60 DAP. Approximately 200 mm of irrigation was provided 53 DAP in 2002. The amount of precipitation from 60 to 100 DAP was 336 and 306 mm for 2001 and 2002, respectively. Ultimately, it was determined the moisture received from the combined precipitation and irrigation amounts were equivalent for both years.

Temperature is important in controlling growth rates (Gipson, 1986; Ohlendorf et al., 1996). The trends for daily DD60s and cumulative DD60s differed between years (Figs. 21 and 22). The increased rate of DD60 accumulation for 2001 from 60 to 100 DAP (Fig. 22) provides a potential explanation for the steeper rate approaching cutout observed in 2001 (Fig.19). In 2001, 1,865 and 1,927 DD60s had accumulated at 100 DAP for 2001 and 2002, respectively. The increase from 60 to 100 DAP was greater for 2001, with 946 DD60s accumulating during that period. In 2002, 853 DD60s had accumulated from 60 to 100 DAP. The increase in heat unit accumulation for 2001 provides evidence to corroborate the steeper slope observed for rate of 2001 crop maturity. Relative to this point, both crops achieved five NAWF at 95 DAP.

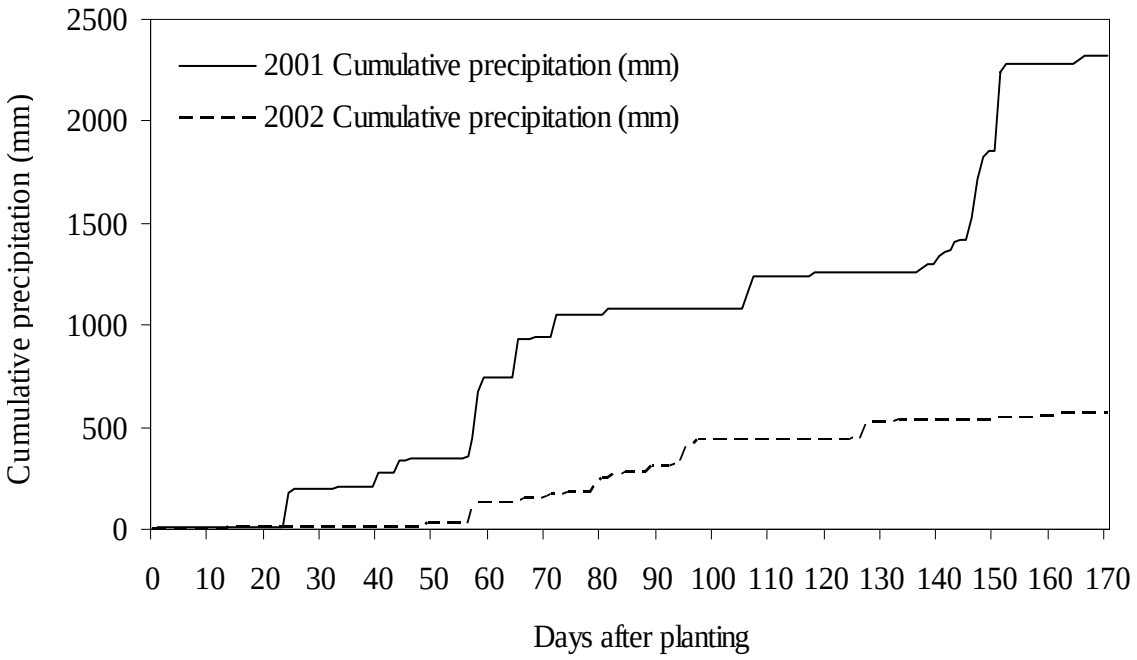

Fig. 20. Cumulative precipitation for the 2001 and 2002 field studies from planting to harvest.

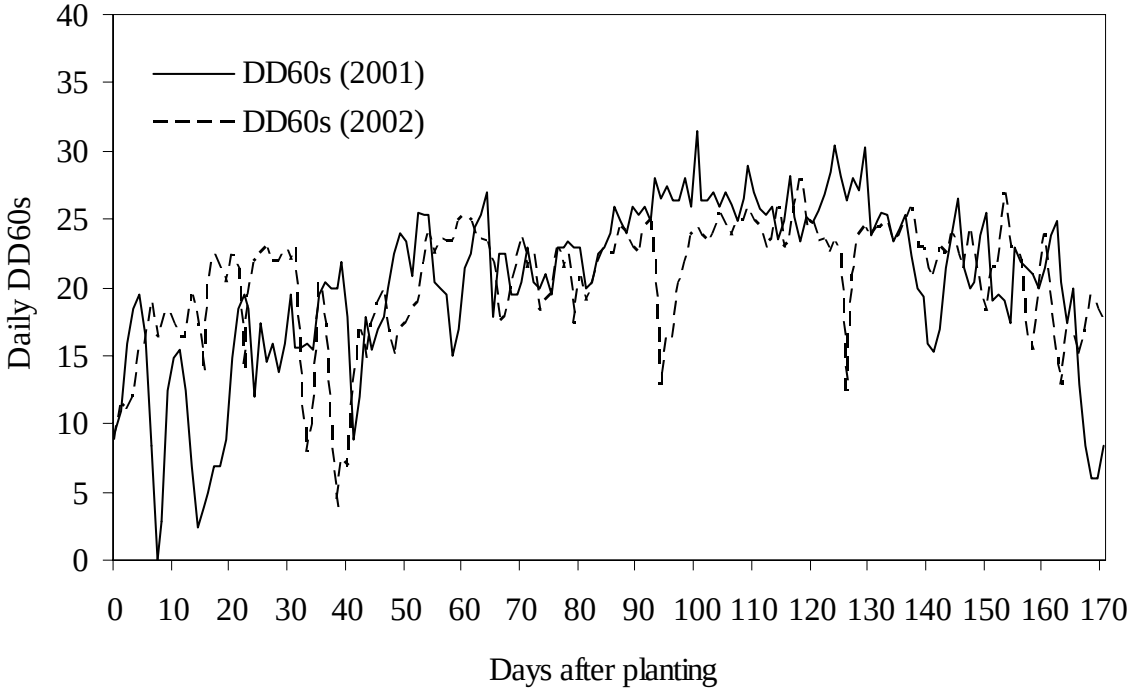

Fig. 21. Daily growing degree days (DD60s) for the 2001 and 2002 field studies from planting to harvest.

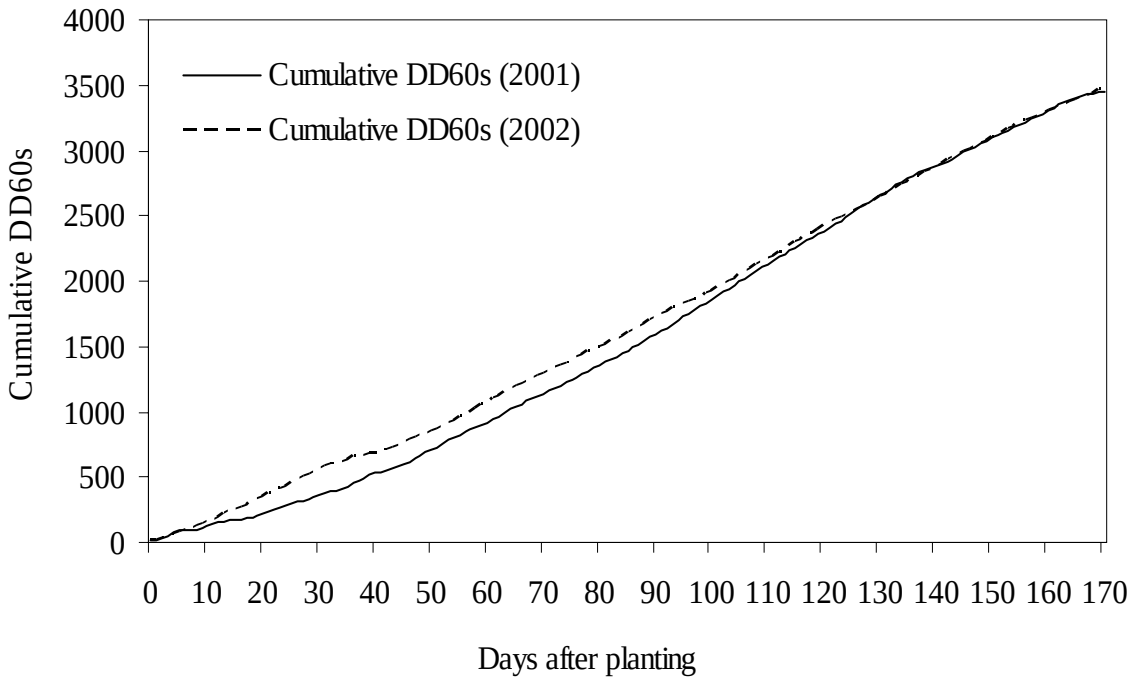

Fig. 22. Cumulative growing degree days (DD60s) for the 2001 and 2002 field studies from planting to harvest.

Neither cotton cultivar nor IR treatments had any effect on NAWF throughout the growing season (Figs. 23 and 24, respectively). The slopes for the regression lines of the three cultivars and IR treatments were not different. In addition, the value for NAWF did not differ at any time during the season for either cultivar or IR main effects.

Plant Biomass Partitioning – Peak Bloom

Partitioning of plant biomass was evaluated one week prior to peak bloom (85 and 81 DAP, in 2001 and 2002, respectively) to assess the effects of cultivar and IR treatments on accumulated biomass and differential partitioning throughout the plant. In addition, this data provides an early assessment about yield trends regarding boll numbers, mean boll weight, and total boll weight. Parameters evaluated included dry weight of leaves, stems, squares, and bolls. Additionally, number of squares and bolls were also recorded.

Leaf dry weight was 2.6 g plant^{-1} greater (P=0.0938) for ST4793R compared to ST474 (Fig. 25). ST892BR was not different from either of the other two cultivars. A similar trend was evident with stem biomass. ST4793R partitioned 4.4 g more biomass plant $^{-1}$ into the stem than ST474 (Fig. 26). Again, ST4892BR was not different from either ST4793R or ST474.

Neither leaf nor stem biomass were affected by IR applications (Figs. 27 and 28, respectively). Slight numerical differences exist for these parameters, favoring NP+FP and OP over NP; however high variability in the data resulted in a lack of statistical significance. Leaf biomass ranged from 23.69 to 25.37 g plant^{-1} for NP and OP,

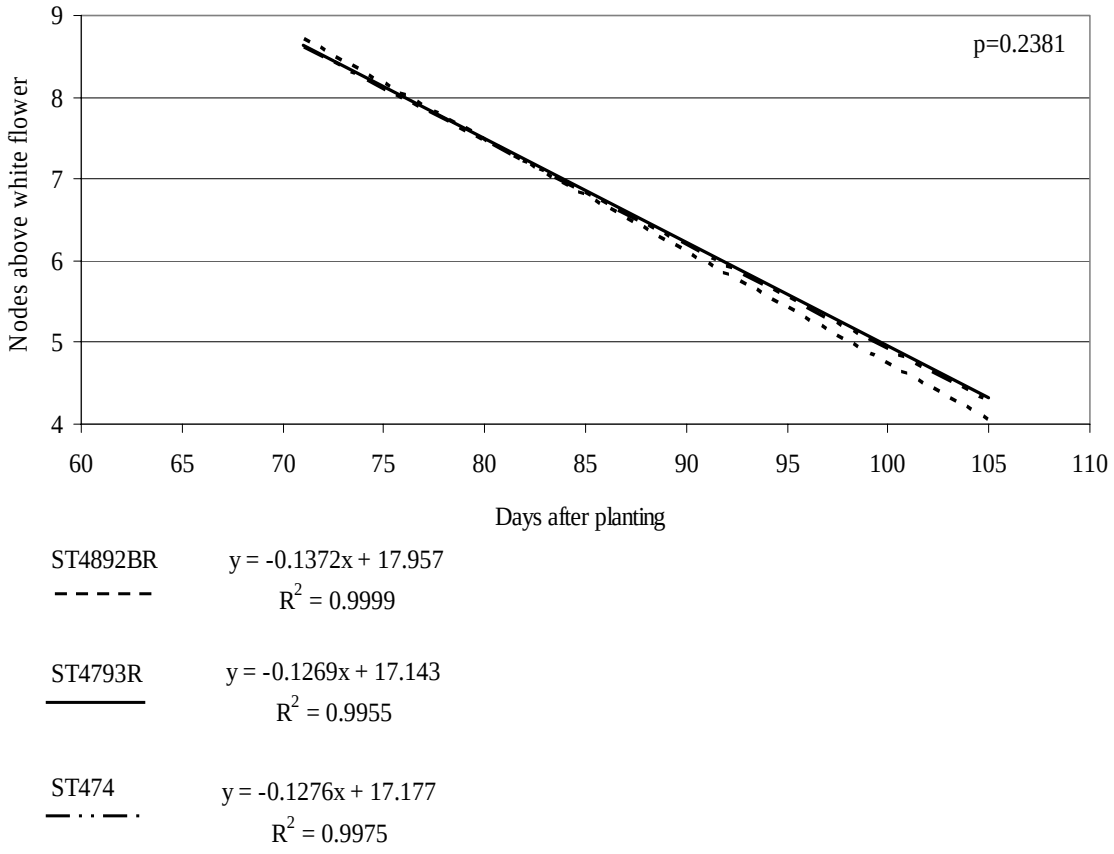

Fig. 23. Average nodes above first position white flower (NAWF) trends combined over years for three cotton cultivars from 70 to 105 days after planting in the field study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines are statistically different at $P<0.05$ according to the analysis of covariance procedure.

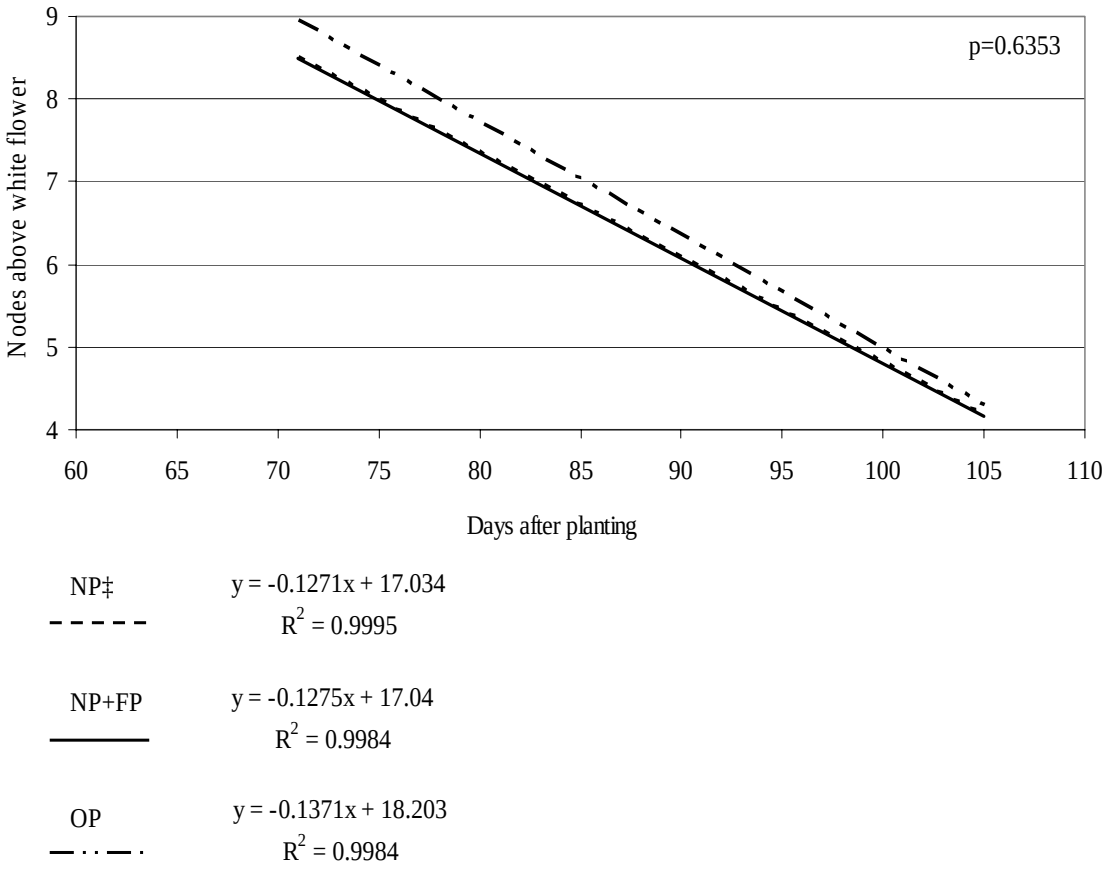

Fig. 24. Average nodes above first position white flower (NAWF) trends combined over years for insecticide regime (IR) treatments from 70 to 105 days after planting in the field study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines are statistically different at $P<0.05$ according to the analysis of covariance procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

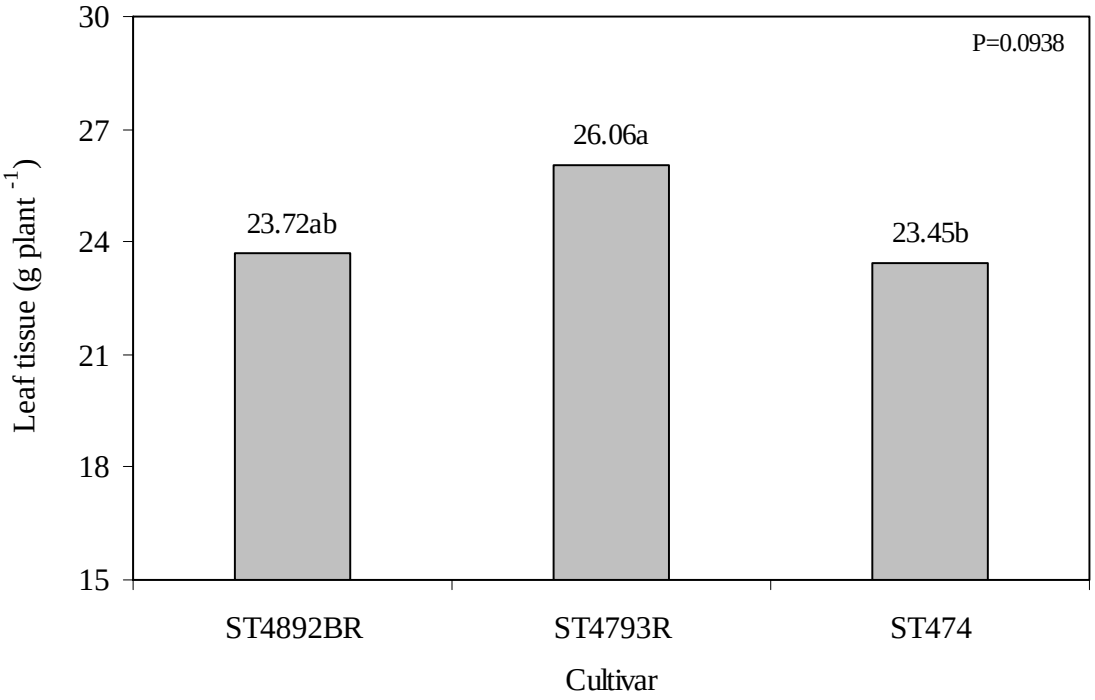

Fig. 25. Dry weight of leaf tissue per plant combined over years for three cotton cultivars at peak bloom in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

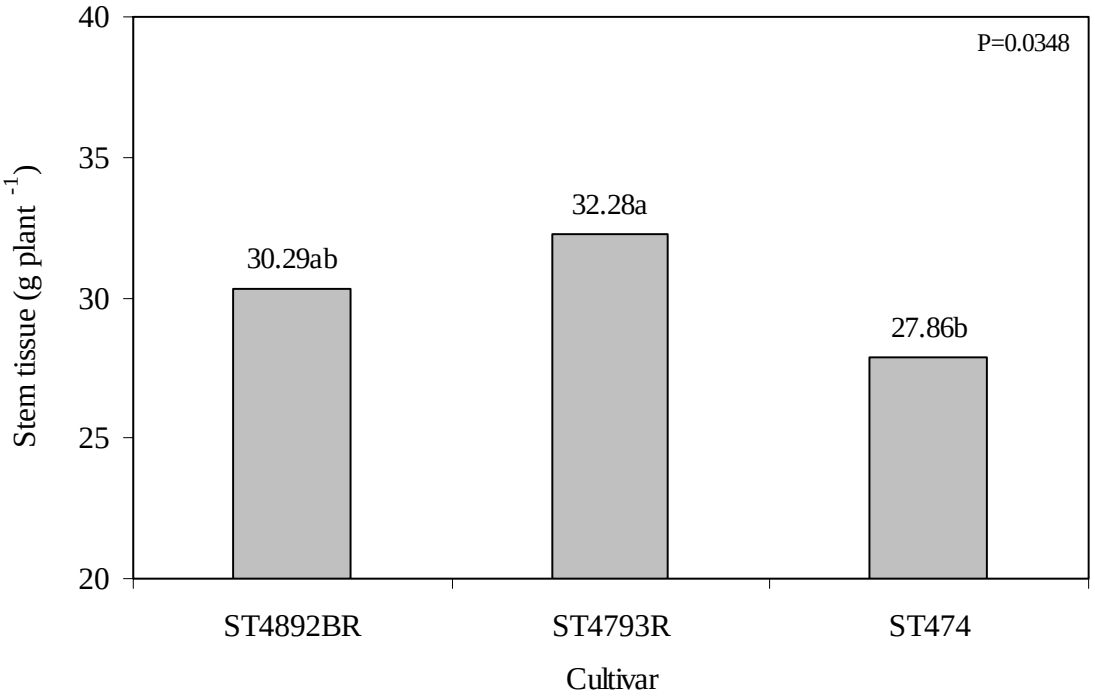

Fig. 26. Dry weight of stem tissue per plant combined over years for three cotton cultivars at peak bloom in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

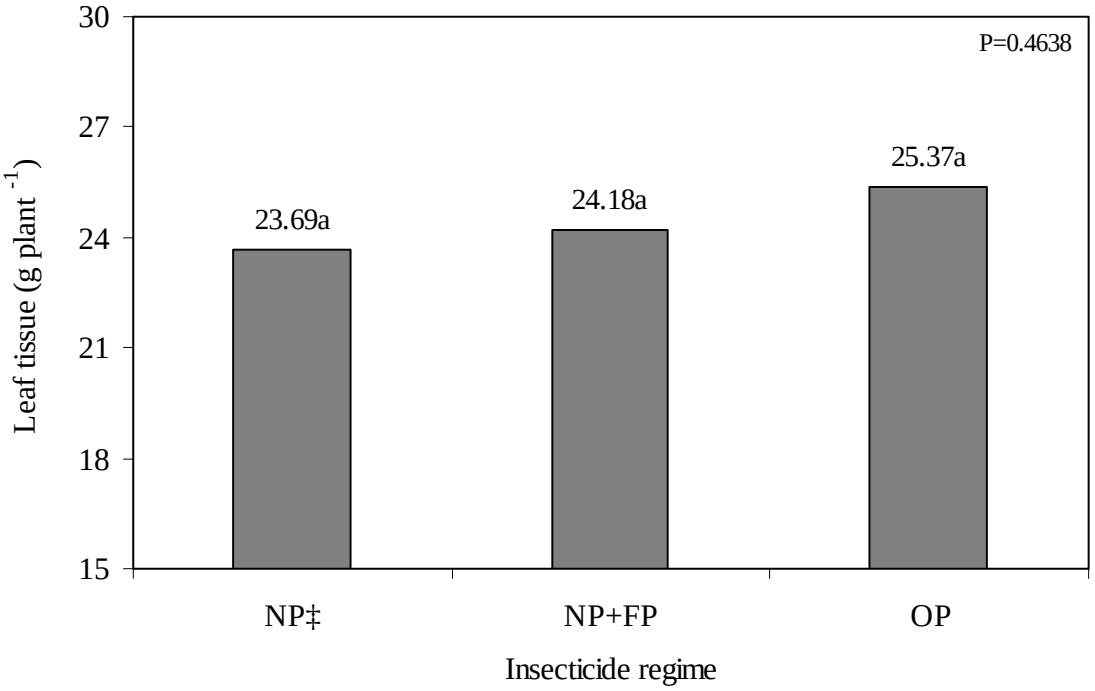

Fig. 27. Dry weight of leaf tissue per plant combined over years for insecticide regime (IR) treatments at peak bloom in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

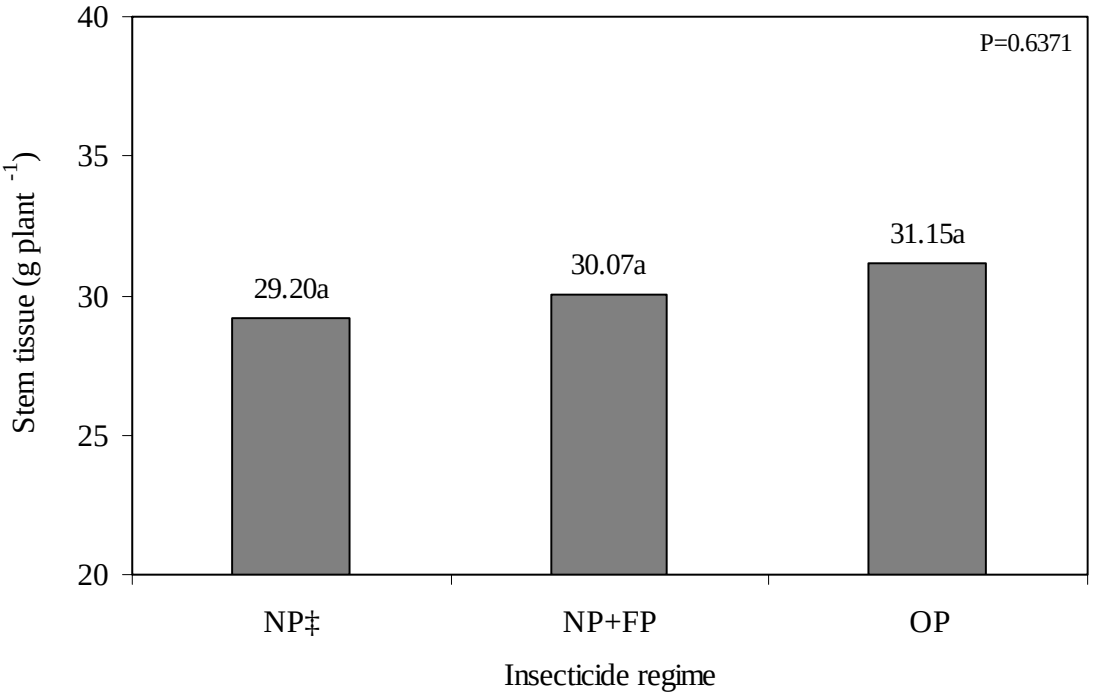

Fig. 28. Dry weight of stem tissue per plant combined over years for insecticide regime (IR) treatments at peak bloom in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

respectively. Stem biomass for NP, NP+FP, and OP was 29.20, 30.07, and 31.15 g plant^{-1}, respectively.

Biomass partitioning of leaves and stems did not differ between the two years (Data not shown). At peak bloom, total square biomass and number of squares were significantly greater in 2001 (Figs. 29 and 30, respectively). However, the 2002 crop had more bolls present at peak bloom (Fig. 31). Averaged across cultivar and IR treatments, mean boll weight plant^{-1} was approximately 0.65 g for both years. The significant increase in boll numbers plant^{-1} observed for the 2002 crop resulted in greater total boll biomass plant^{-1} (Fig. 32).

Dry weight of total squares plant^{-1} for each cultivar was 2.15, 2.50, and 2.12 g for ST4892BR, ST4793R, and ST474, respectively (Fig. 33). Approximately 0.4 g more (P=0.0898) dry weight plant^{-1} was partitioned into squares for ST4793R than for the other two cultivars. Dry weight for squares was not different for ST4893BR and ST474. Mean square weight plant^{-1} was approximately 0.1 g for all three cultivars (Fig. 34). Total square numbers plant^{-1} for the three cultivars were not different (P=0.1375), although numerical trends are evident (Fig. 35). This data follows the same trend exhibited by total square biomass indicating that the numerical increase in square numbers for ST4793R led to the significant increase observed for total square weight.

At peak bloom, ST4892BR had 1.1 g greater (P=0.0867) total boll dry weight plant $^{-1}$ than the other two cultivars (Fig. 36). Mean boll weight plant^{-1} was approximately 0.7 g for all three cultivars (Fig. 37). Cultivar effect on total boll numbers was not statistically different (Fig. 38). However, the positive numerical trend

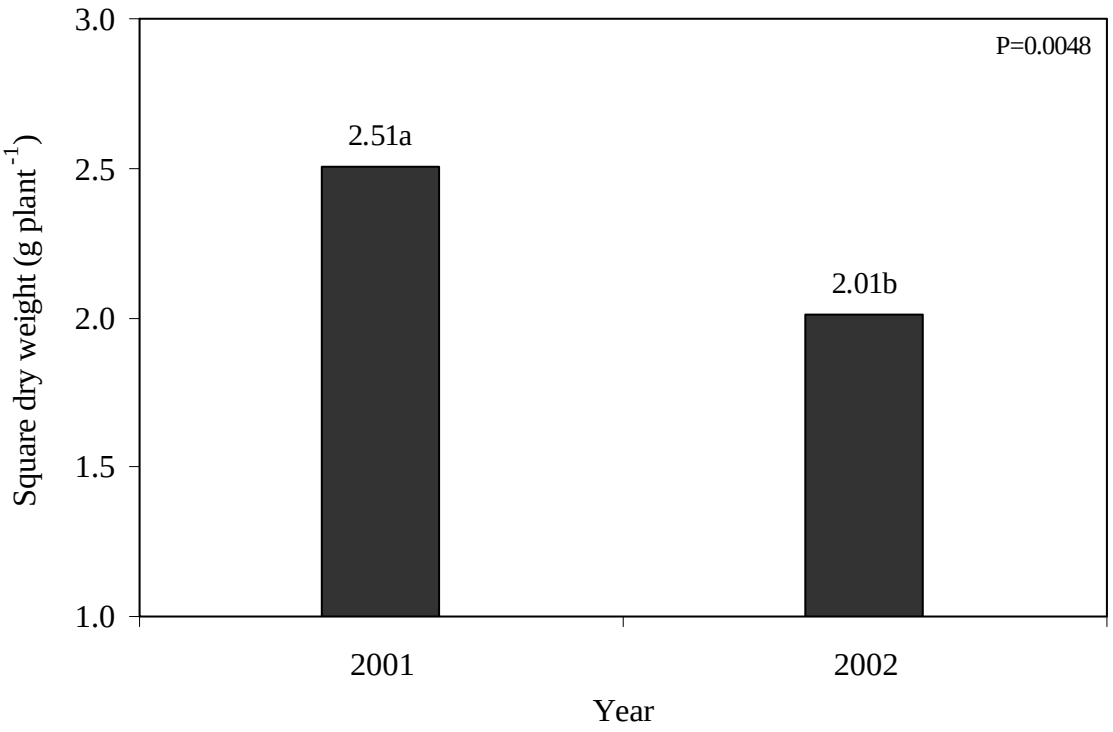

Fig. 29. Total square dry weight per plant at peak bloom for the 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

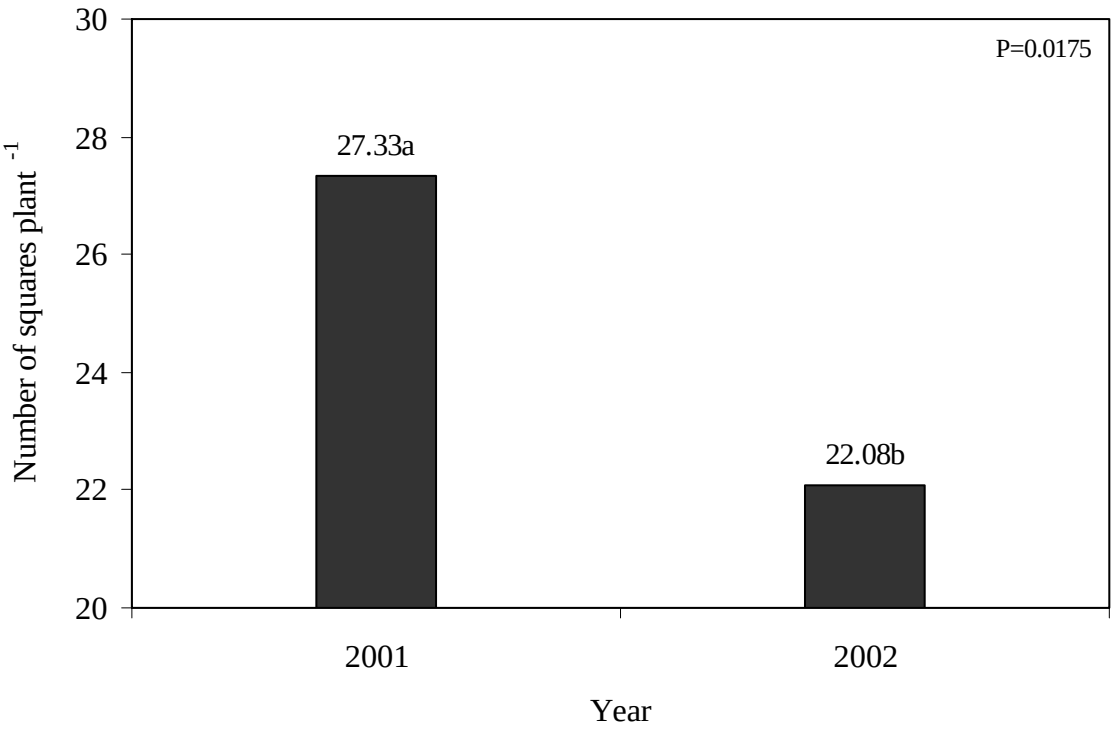

Fig. 30. Total number of squares per plant at peak bloom for the 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

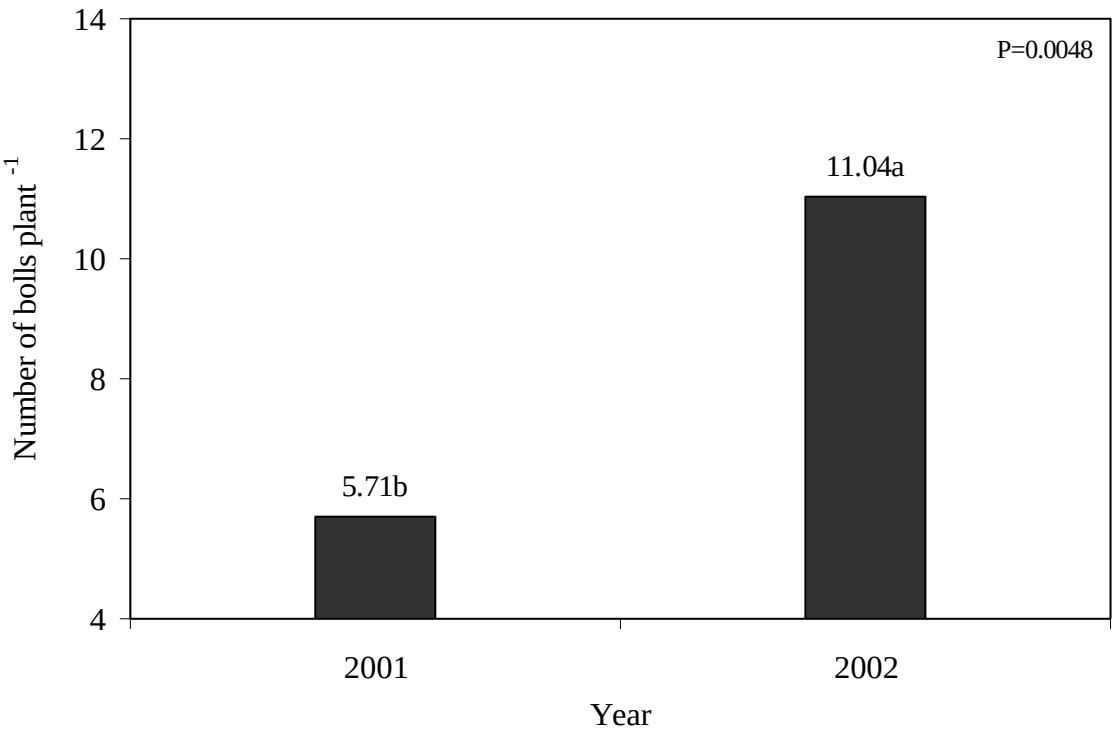

Fig. 31. Total number of bolls per plant at peak bloom for the 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

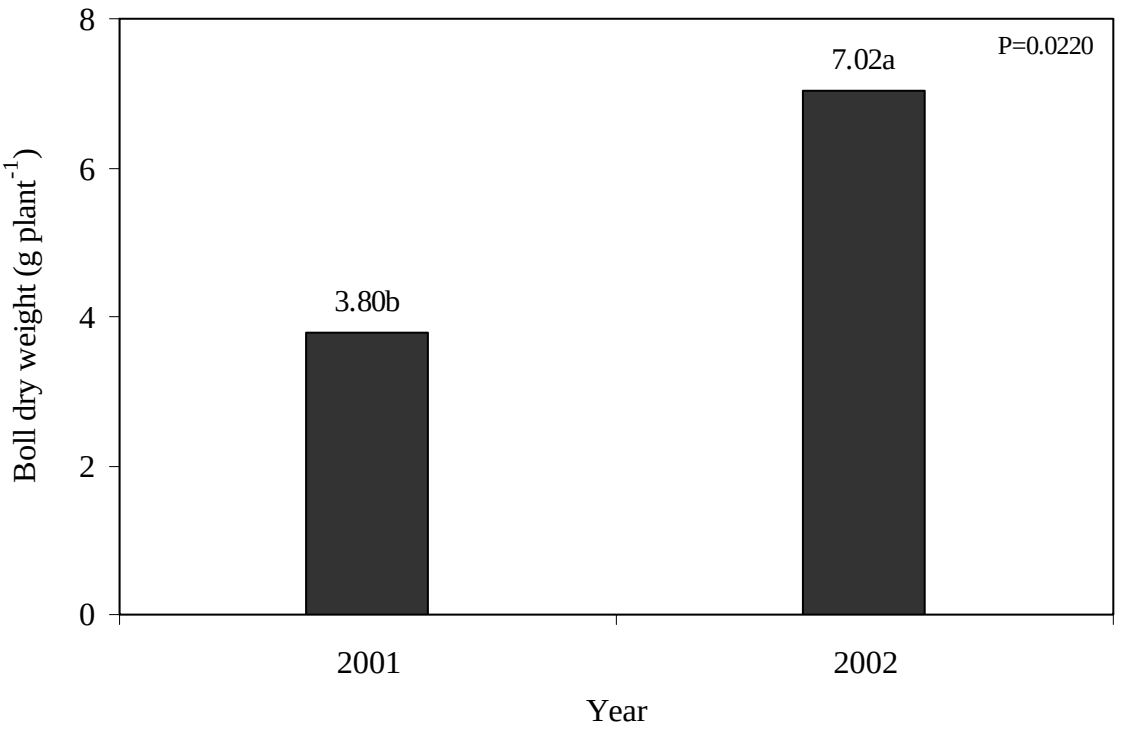

Fig. 32. Total dry weight of bolls per plant at peak bloom for the 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

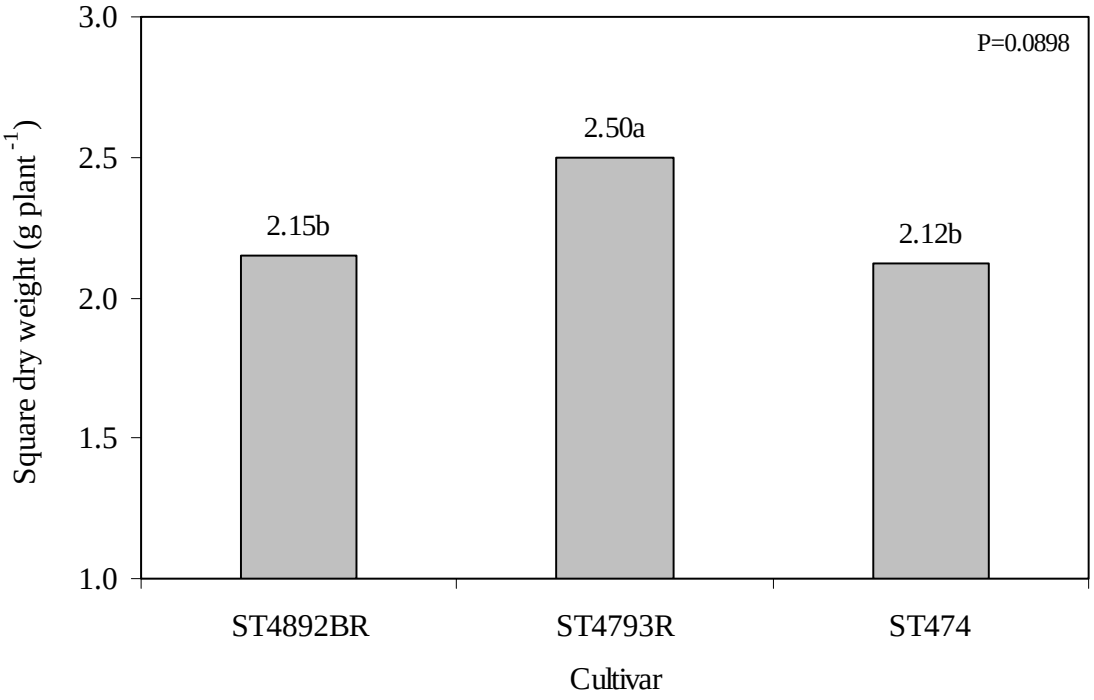

Fig. 33. Total square dry weight per plant combined over years at peak bloom for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

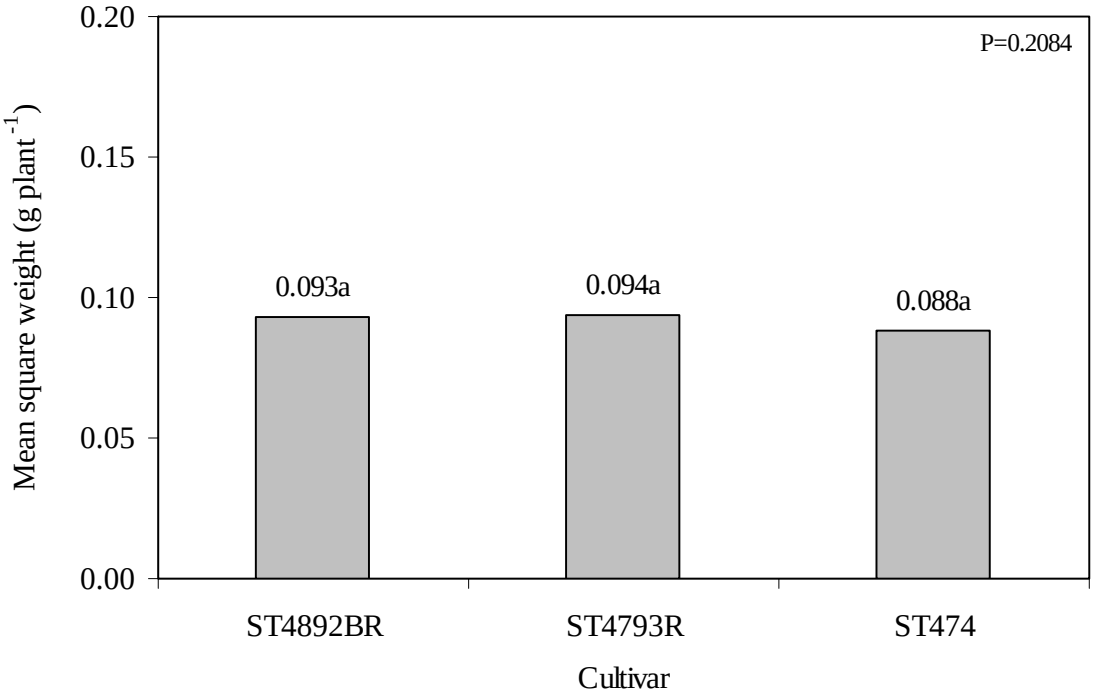

Fig. 34. Mean square dry weight per plant combined over years at peak bloom for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

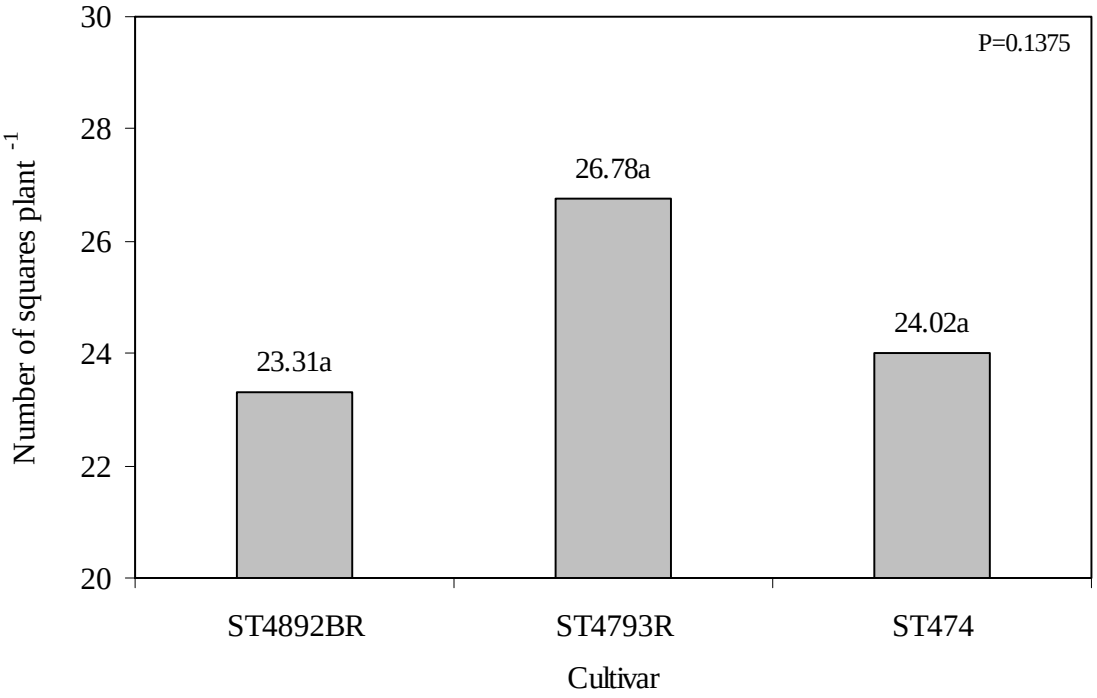

Fig. 35. Total number of squares per plant combined over years at peak bloom for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

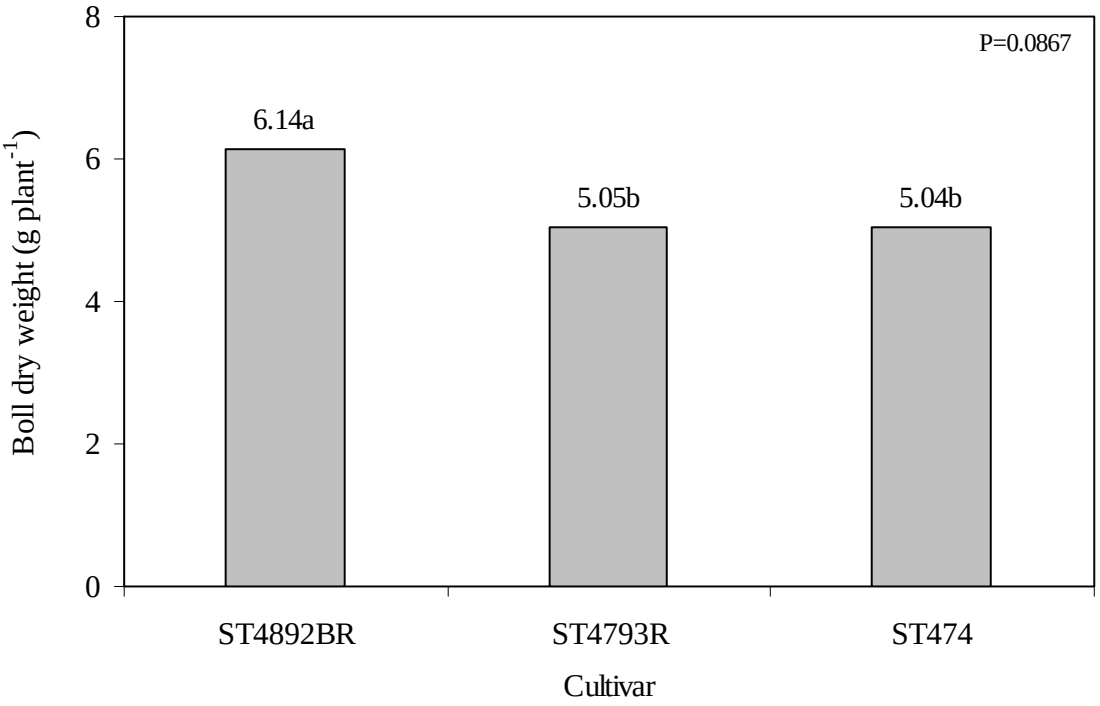

Fig. 36. Total boll dry weight per plant combined over years at peak bloom for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

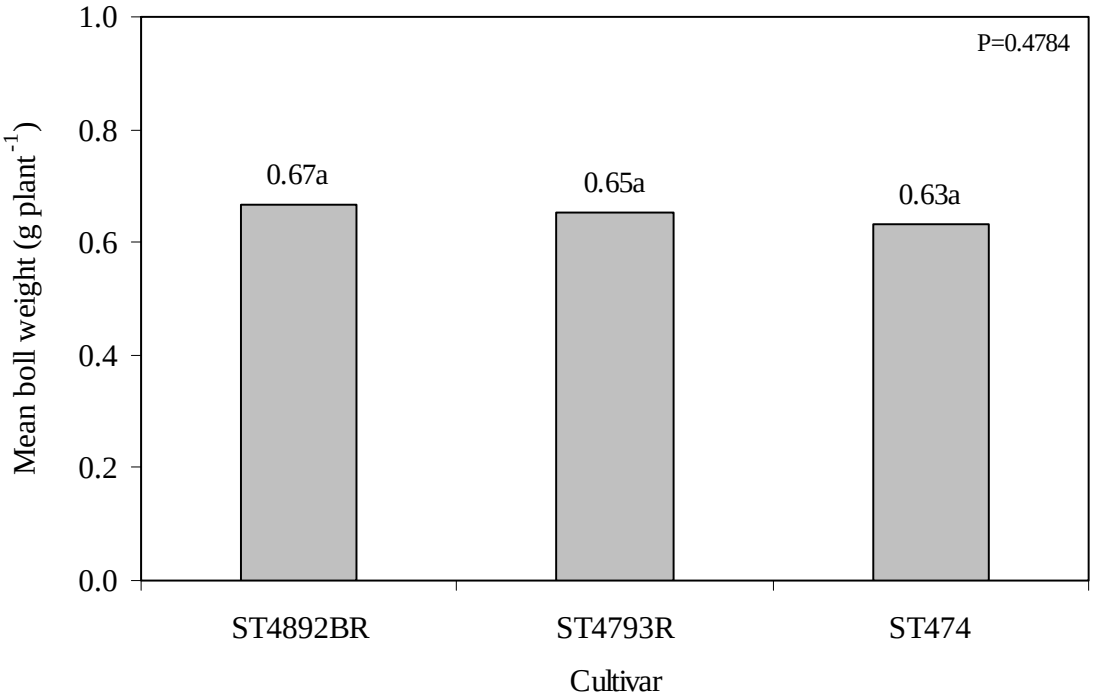

Fig. 37. Mean boll dry weight per plant combined over years at peak bloom for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure.

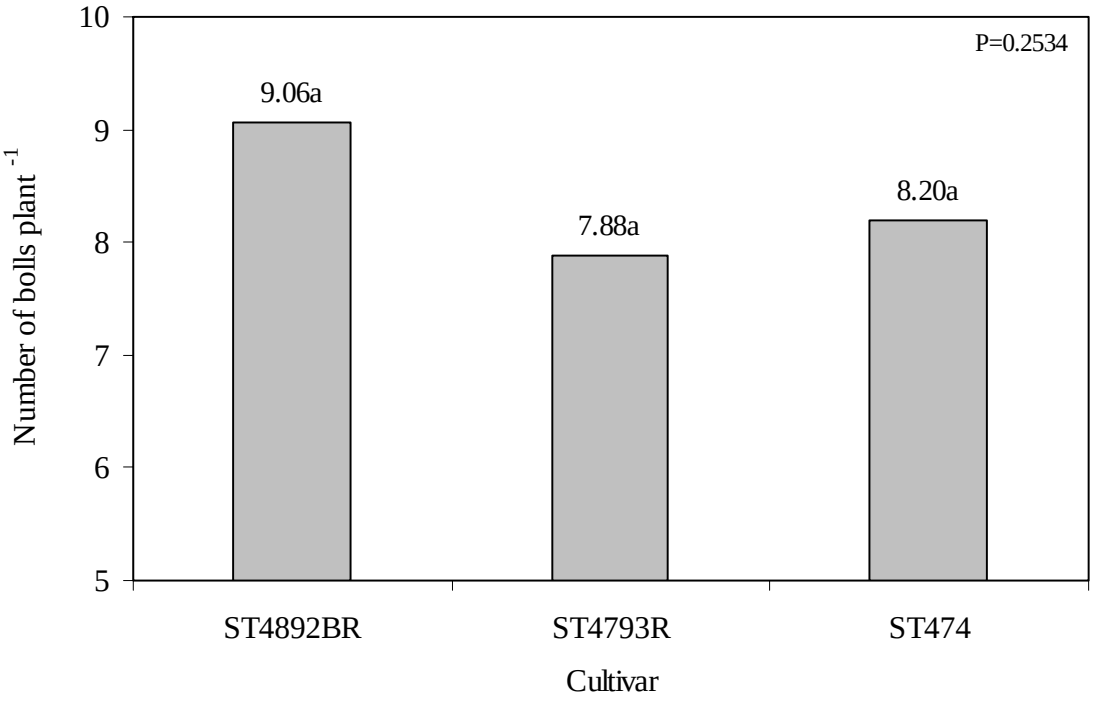

Fig. 38. Total number of bolls per plant combined over years at peak bloom for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

in boll numbers plant^{-1} for ST4892BR and the equal mean boll weights for all cultivars suggest that the trend in boll numbers translated to increased total boll dry weight plant^{-1} for ST4892BR.

Applications of IR treatments slightly affected total square biomass. NP+FP had approximately 0.4 g greater (P=0.1011) total square weight plant^{-1} than NP and OP (Fig. 39). Though no statistical differences exist for total square numbers (Fig. 40), the numerical trends likely translated into the results observed for total square biomass. IR treatments had no effect on mean square weight plant^{-1} (Fig. 41).

Boll numbers and mean boll weight plant^{-1} of cotton at peak bloom were not significantly affected by applications of IR treatments (Figs. 42 and 43, respectively). This observation is further supported by the lack of variation in total boll dry weight plant^{-1} between IR treatments (Fig. 44). A numerical trend existed for NP+FP, with that treatment having approximately one more additional boll per plant than the other IR treatments. At peak bloom, this trend had no influence on ultimate total boll biomass; however, if the NP+FP treatment matures one additional boll plant^{-1}, a substantial yield increase could be realized. In a population of 114,000 plants ha^{-1}, the one boll plant^{-1} (assuming a 4 g boll^{-1} mean weight) could mean a 456 kg ha^{-1} increase in seedcotton yield for the NP+FP treatment. The trend for additional fruit plant^{-1} is further reflected in fruit dry weight as a percent of total plant biomass. Though not statistically different, NP+FP had a numerically greater percent of biomass partitioned to fruit than NP and OP, with values of 12.8, 12.5, and 11.8 percent, respectively (Fig. 45).

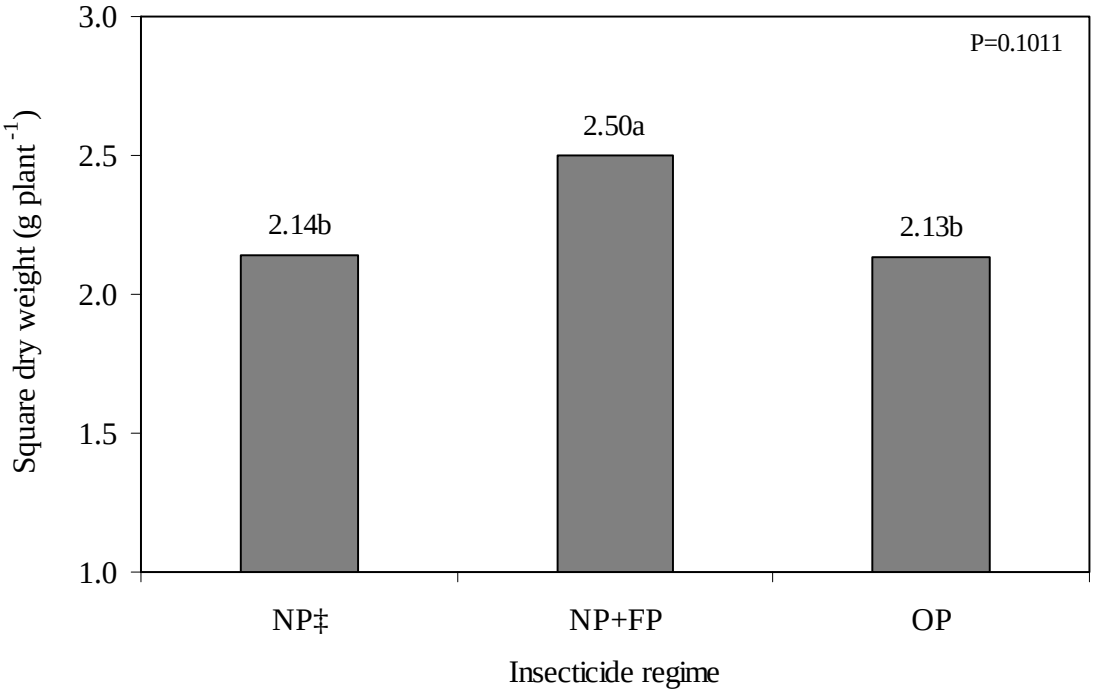

Fig. 39. Total square dry weight per plant combined over years at peak bloom for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

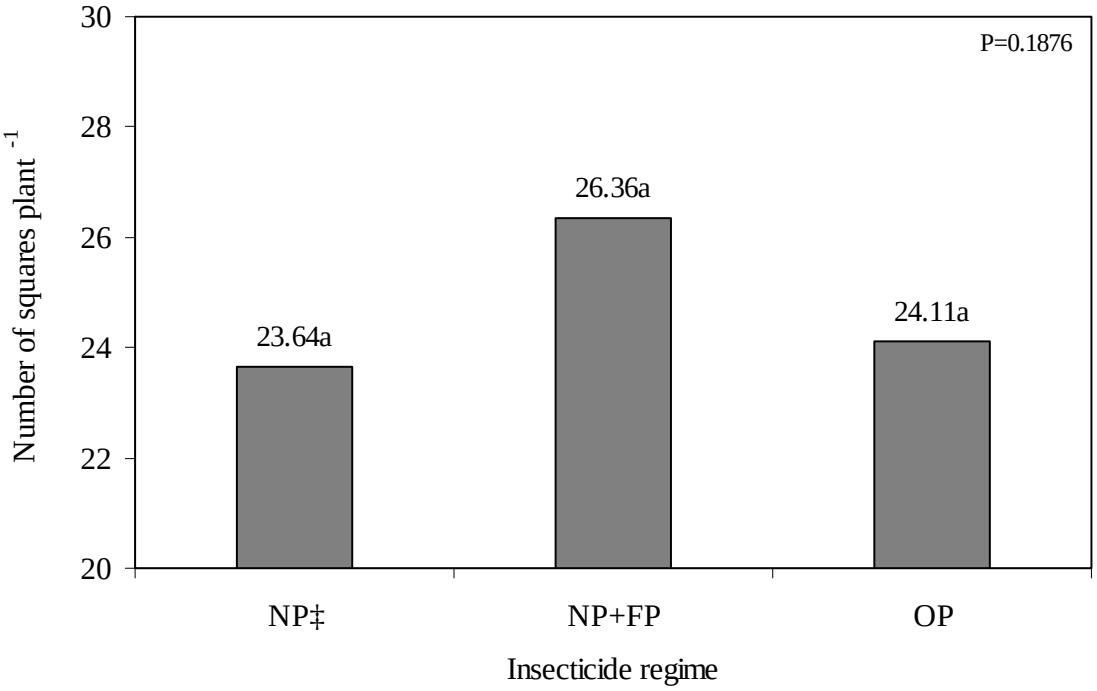

Fig. 40. Total number of squares per plant combined over years at peak bloom for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

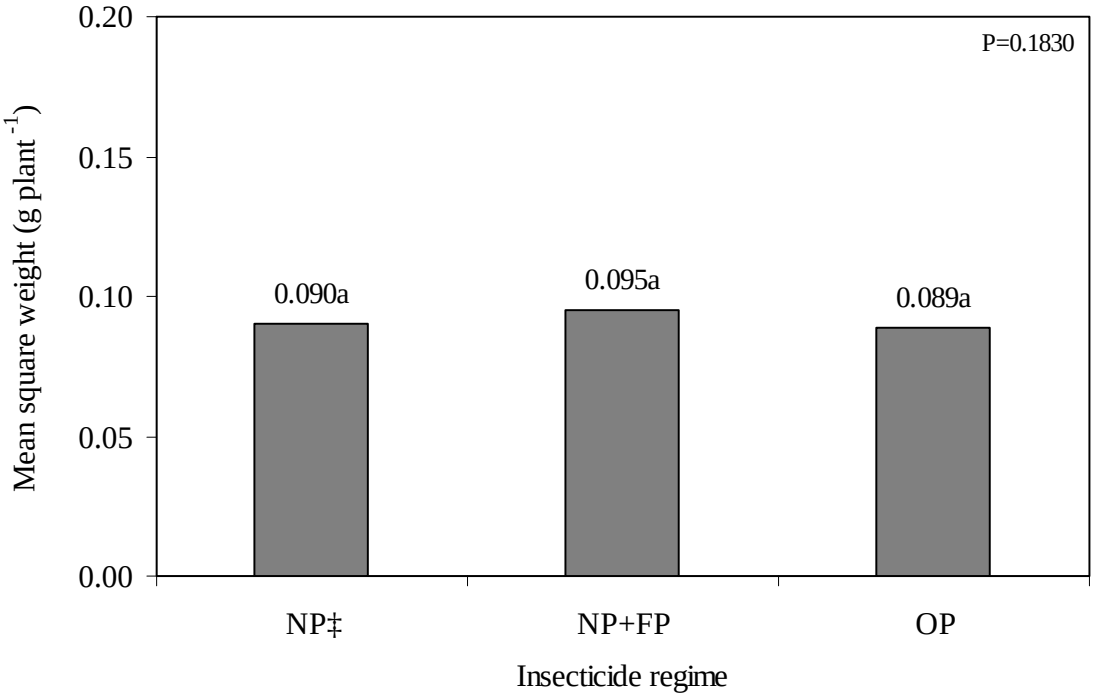

Fig. 41. Mean square dry weight per plant combined over years at peak bloom for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

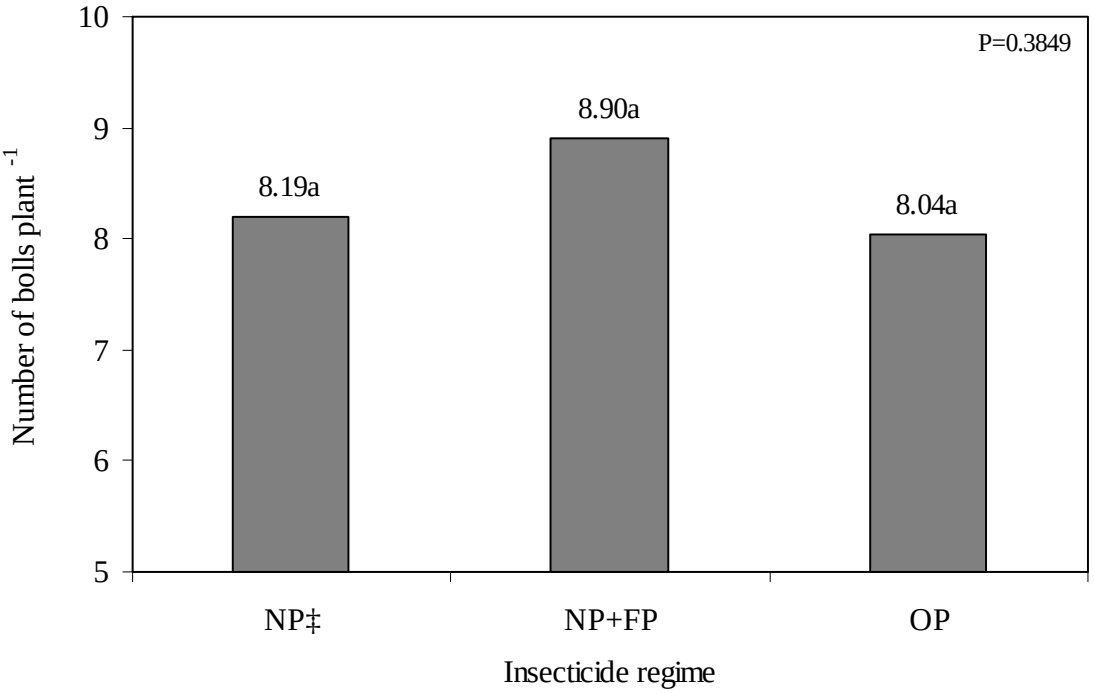

Fig. 42. Total number of bolls per plant combined over years at peak bloom for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

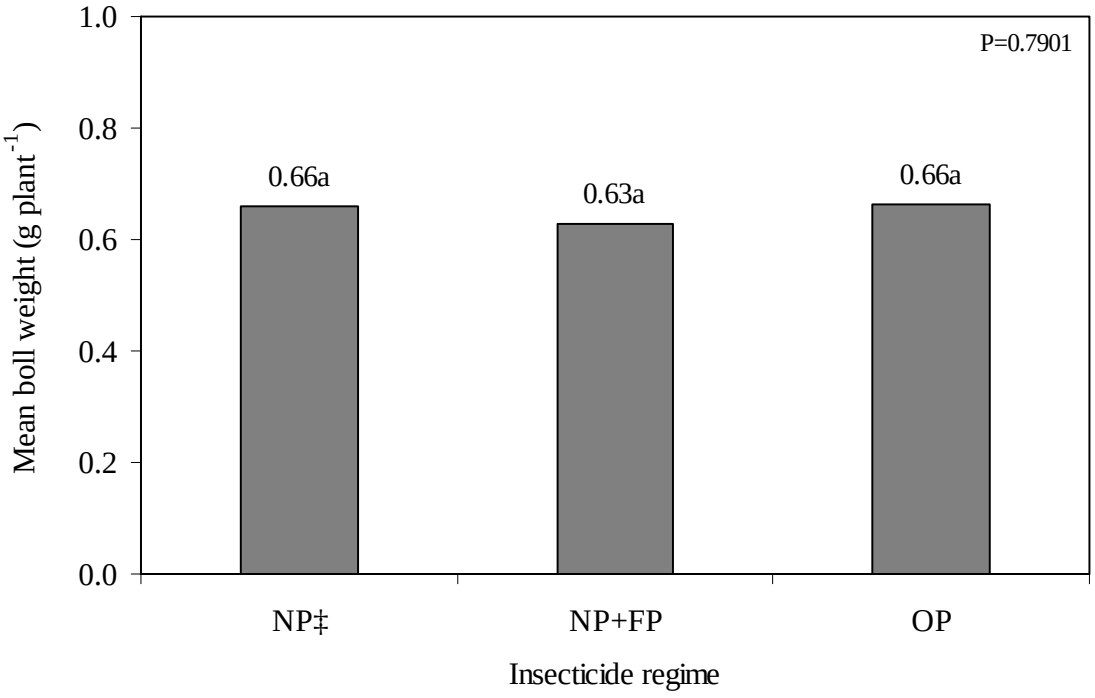

Fig. 43. Mean boll dry weight per plant combined over years at peak bloom for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

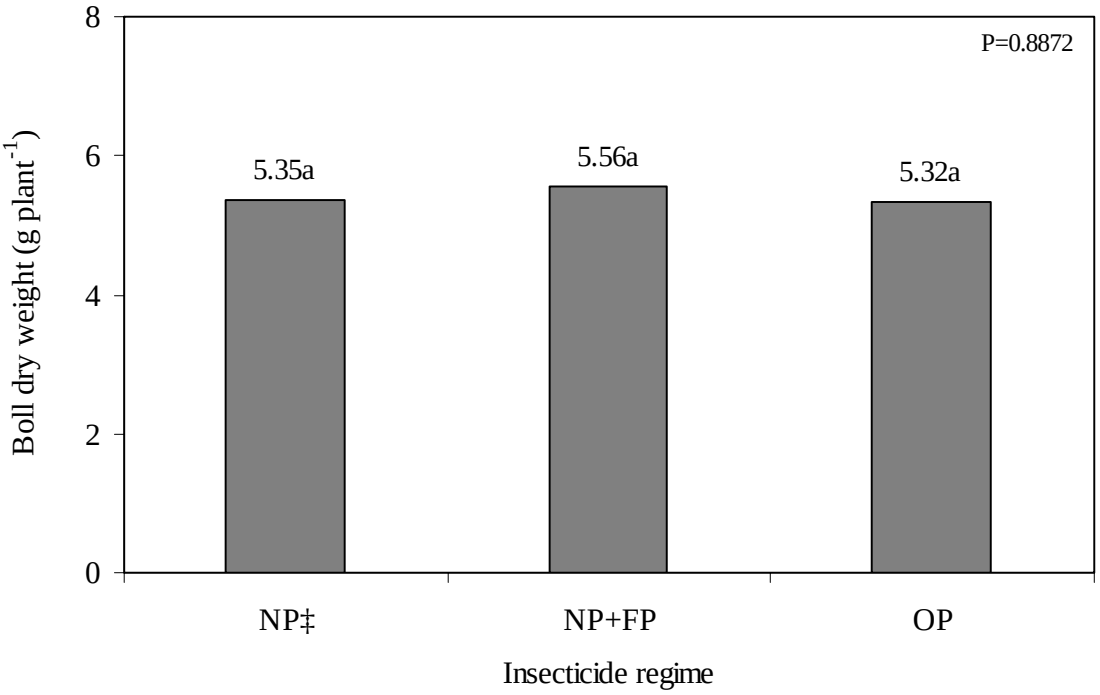

Fig. 44. Total boll dry weight per plant combined over years at peak bloom for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

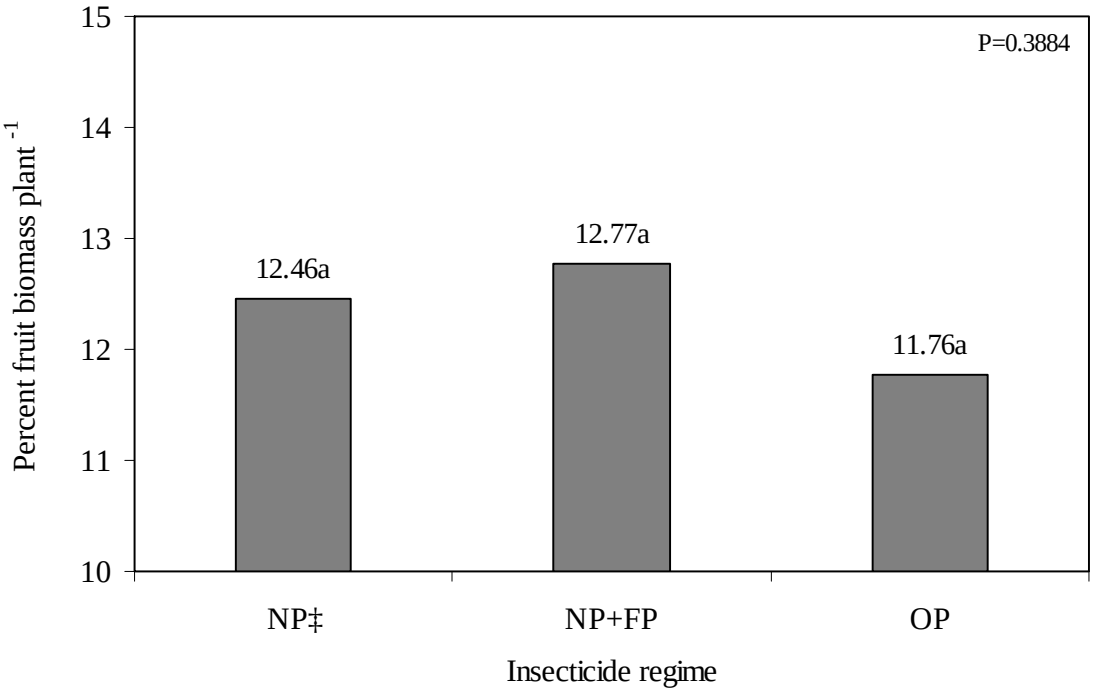

Fig. 45. Percent of total plant biomass partitioned as fruit combined over years at peak bloom for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Generally, cultivar had a greater effect on the partitioning of plant biomass than IR treatments. At peak bloom, data reflects yield trends observed at harvest to a large extent. ST4892BR had approximately 1.5 % more (P=0.0853) biomass partitioned to fruit than ST4793R (Fig. 46). ST474 was not significantly different from the other two cultivars in the amount of fruit biomass. However, ST474 had a numerically lower percent of biomass partitioned as fruit than did ST4892BR. Noting this disparity is important as it becomes more exaggerated as the season progresses and ultimately results in the statistical differences observed in yield at harvest.

Plant Mapping - Harvest

Examining plant biomass partitioning at peak bloom provided insight into allocation of carbon into vegetative and reproductive biomass. The results from that assessment indicated potential yield trends based on the amount of fruit biomass present for the respective treatments. However, trends are indications at best and must continue until harvest for realization of yield differences. Many factors, including environmental effects, can alter fruiting patterns and distribution between peak bloom and harvest. Factors such as insect pressure and water stress were controlled as best possible to reduce these variables as sources affecting the performance of cultivar and efficacy of IR treatments.

Knowledge of developmental patterns of fruiting structures throughout the growing season is important to understanding the variation in boll numbers and size among fruiting branches and intra-sympodial fruiting sites. New fruiting branches are produced at approximately 3-day intervals, and initiation of fruiting positions on the

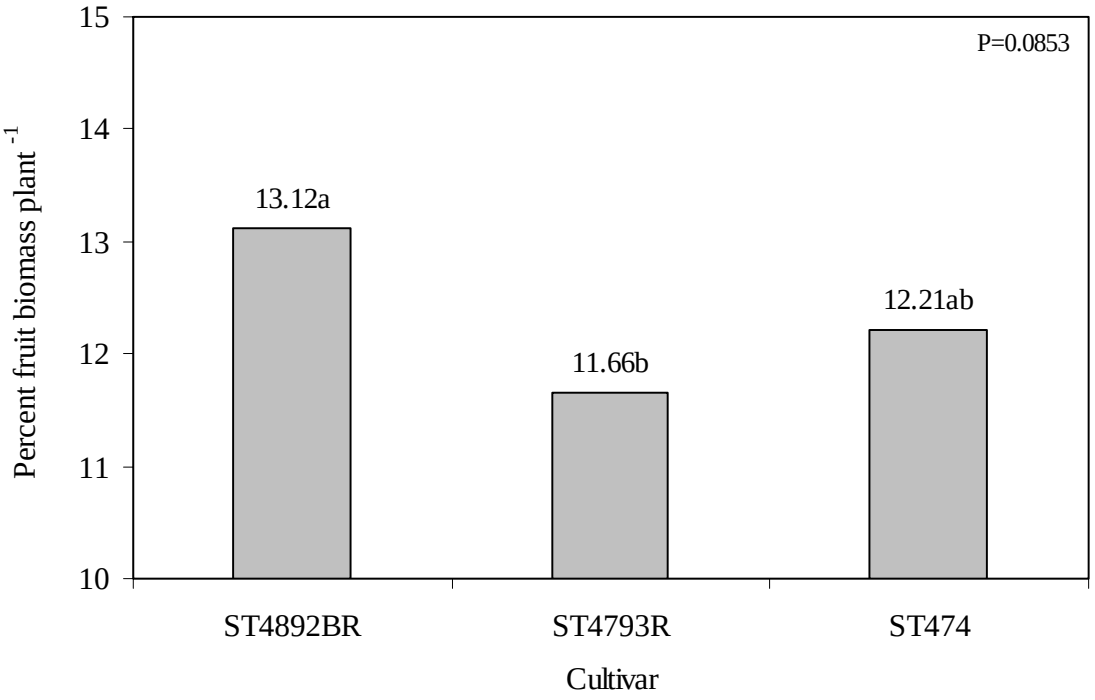

Fig. 46. Percent of total plant biomass partitioned as fruit combined over years at peak bloom for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

same fruiting branch is about 6 days apart (Kerby and Hake, 1996). The location of bolls within the plant architecture has a substantial effect on their size. Bolls located on lower sympodia are generally larger than those positioned higher on the plant. Boll position on any given sympodial branch also affects their size. First position bolls are the strongest sink for carbon allocation, and therefore have potentially greater impact on crop yield (Ashley, 1972; Wullschleger and Oosterhuis, 1990). The physiological effect of sink strength causes bolls at more distal positions to be successively smaller (Kerby and Ruppenicker, 1992; Parvin and Atkins, 1997). Research by Jenkins et al. (1990a) attributed the reduced size of second and third position bolls to preferential partitioning of photosynthate to first position fruit during development. The effect of location on boll size is related to the morphological sequence in which cotton initiates flowers from lower to higher sympodia and also out to successive positions on sympodial nodes. In mid-South cotton, the bolls at first and second position fruiting sites on sympodial branches typically produce from 50 to 75% and 15 to 20%, respectively, of the total yield, with the remaining 5 to 15% occurring at more distal positions and on monopodial branches (Jenkins et al., 1990b; Boquet et al., 1994). Furthermore, Boquet and Moser (2003) suggested that the competitive edge exhibited by first position bolls may also be related to enhanced access to nutrients and water because of their proximity to the main stem, which results in larger and more efficient subtending leaves. Demonstration of this relationship was made using ^{14}C labeling technology to illustrate that the predominant source of photosynthate for a boll was its subtending leaf and the primary sink on a given sympodium was first position fruit (Benedict and Kohel, 1975).

Plant mapping at harvest more clearly documents the fruiting architecture contributing to any yield variations found in this study. Specifically, this mapping technique dissects the distribution of yield components into nodal and fruiting positions. Mapping data is collected by separating harvestable bolls into plastic buckets assigned a designated fruiting position number and nodal range. This plant mapping technique is alternatively called box mapping because of the use of "boxes" to separate and collect the bolls for analysis. The number of bolls and total weight of seedcotton for each nodal range and position within the range were recorded during the procedure. In addition, plant height, number of nodes, and first reproductive node were also documented.

Examination of trends in plant growth during the season from cutout until harvest resulted in little difference in plant height between the three cultivars. No statistical differences existed (P=0.1177); however, numerical trends followed those defined in the data at cutout with ST4892BR, ST4793R, and ST474 having heights of 105.4, 98.9, and 99.5 cm, respectively (Fig. 47). Increases in the number of nodes per plant for the three cultivars were also consistent during this period, resulting in no differences between cultivars at harvest. All three cultivars had approximately 26 nodes at harvest (Fig. 48). The numerical differences in plant height at harvest culminated in statistical differences in average internode length. ST4892BR had a longer internode length than ST474 with values of 4.0 and 3.8, respectively (Fig. 49). ST4793R internode length was not different from either of the other two cultivars having an average internode length of 3.9 cm. The trends for average internode length are similar to those observed at cotton cutout.

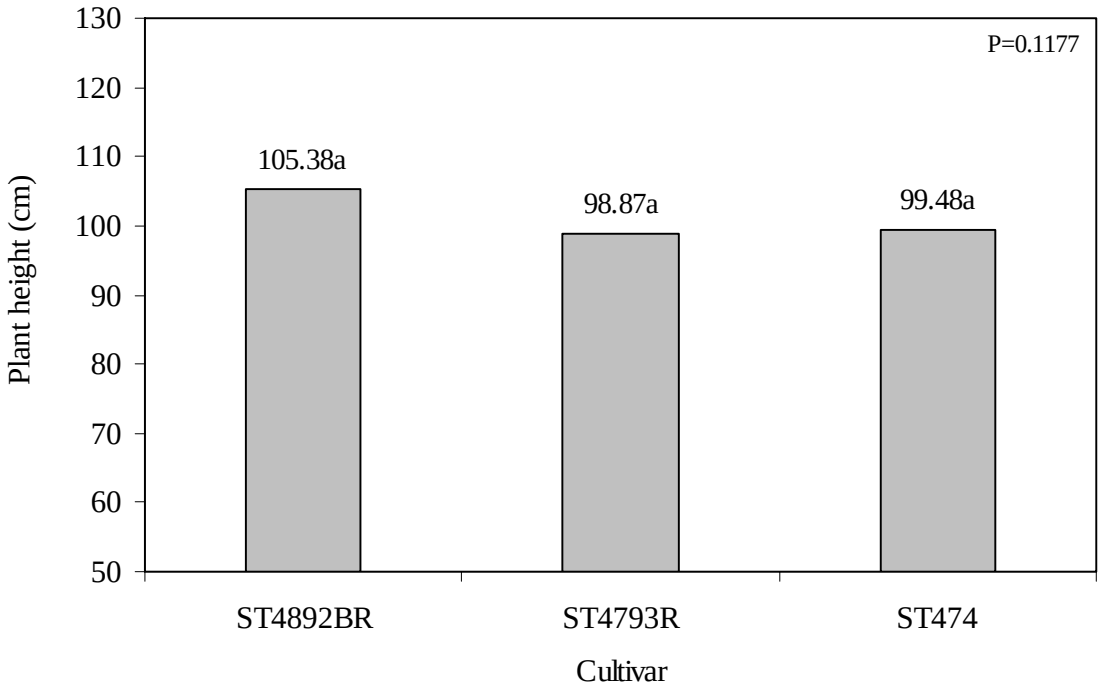

Fig. 47. Plant height combined over years at harvest for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

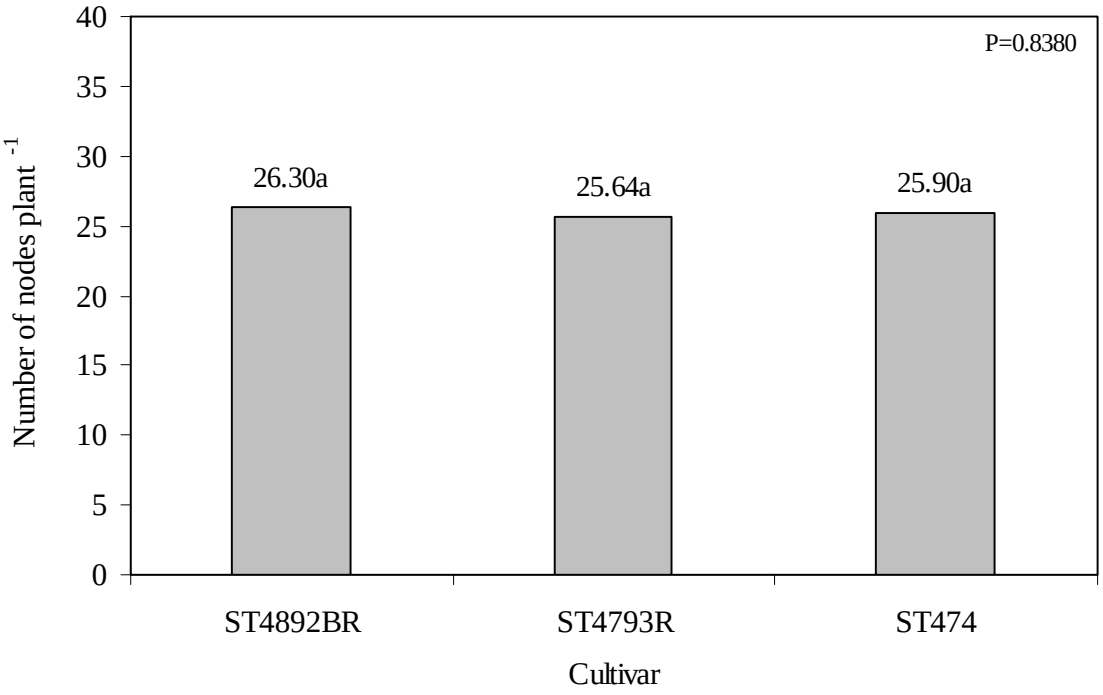

Fig. 48. Number of main-stem nodes combined over years at harvest for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

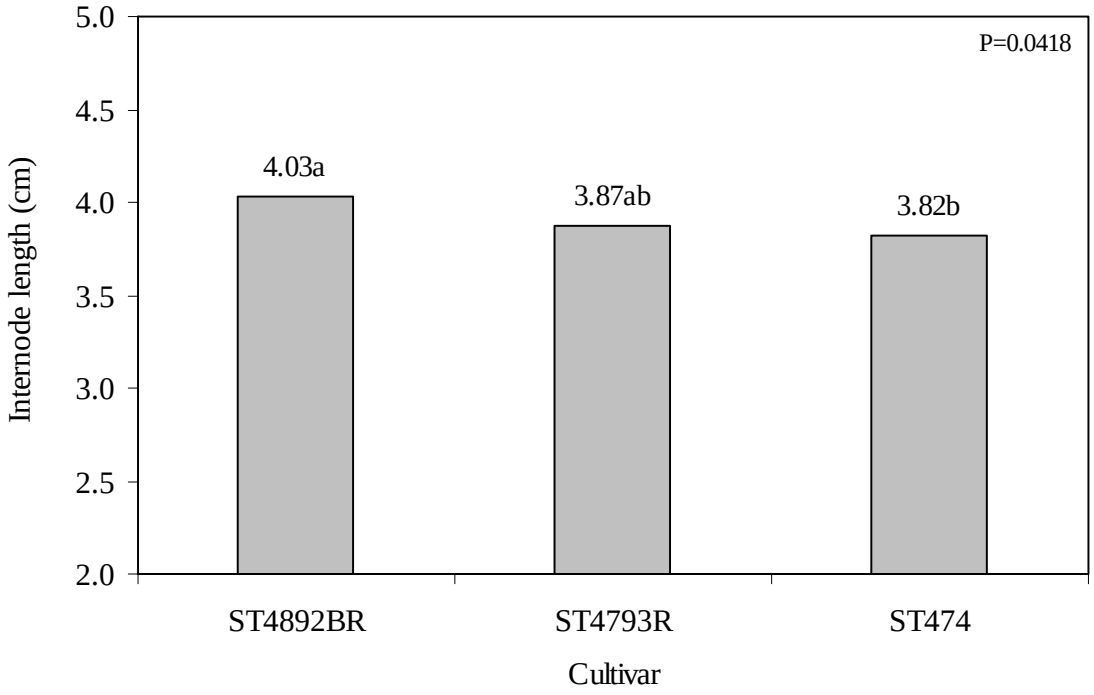

Fig. 49. Average internode length combined over years at harvest for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

Applications of IR treatments did not affect end of season plant height, number of nodes, or average internode length (Figs. 50, 51, and 52, respectively). These statistics are consistent with early and mid-season observations.

The total seedcotton weight recorded through the box mapping procedure includes reproductive as well as vegetative bolls in the calculation. The total seedcotton weight per plant collected from the mapping procedure was consistent with yield trends for all three cultivars. ST4892BR had approximately 10.5 and 11.7 g more seedcotton plant^{-1} than ST4793R and ST474, respectively (Fig. 53). ST4793R and ST474 were not different from each other and produced 57.9 and 56.7 g seedcotton plant^{-1}, respectively.

Application of IR treatments resulted in no statistical differences in seedcotton weights as acquired through box mapping. The numerical trends, however, reflect those observed from harvest data, with NP+FP having the largest seedcotton weight at 63.9 g plant^{-1}, followed by OP and NP with 60.1 and 59.0 g plant^{-1}, respectively (Fig. 54). The data for total seedcotton weight plant^{-1} should reflect measurements of seedcotton yield harvested from the field. However, some instances exhibit larger inherent variability due to the relatively small sample size obtained for the mapping procedure compared to the sample size represented by yield measurements acquired through machine harvest. In research, better estimates of the true mean of a population are acquired by increasing sample size (Ott and Longnecker, 2001). Because of the time and labor involved in box mapping, sample size (six plants) per plot to provide practical and reasonable estimates of the components contributing to final yield was limited. The number of observations included in the sample is a compromise between the desired accuracy of the sample

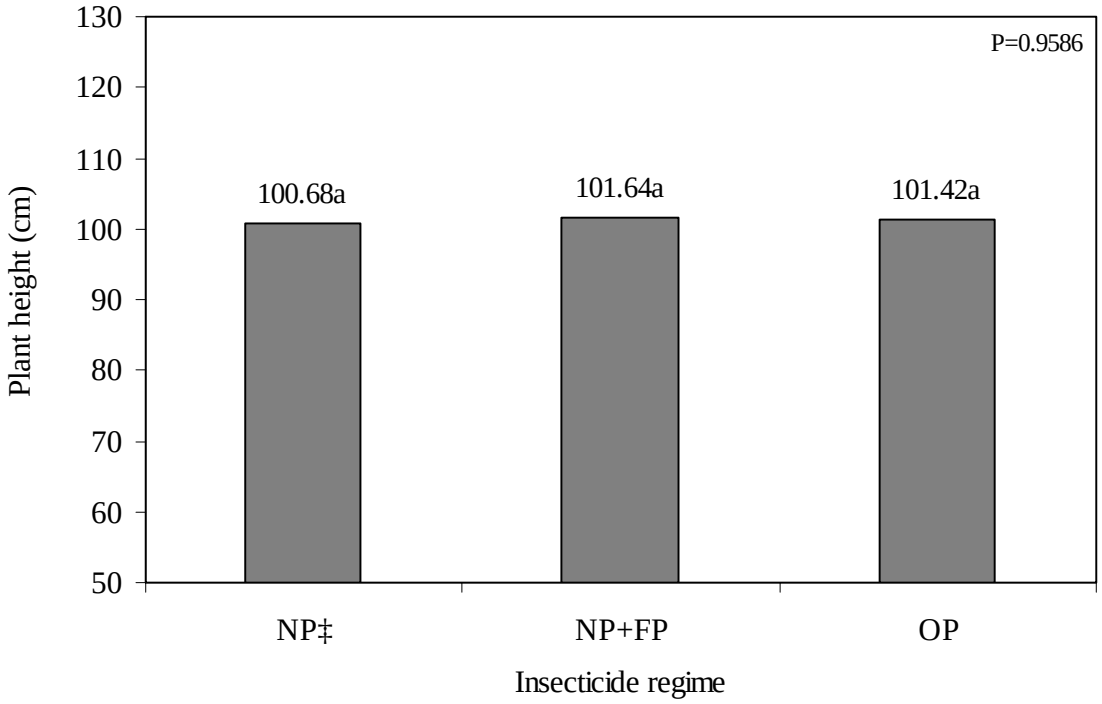

Fig. 50. Plant height combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

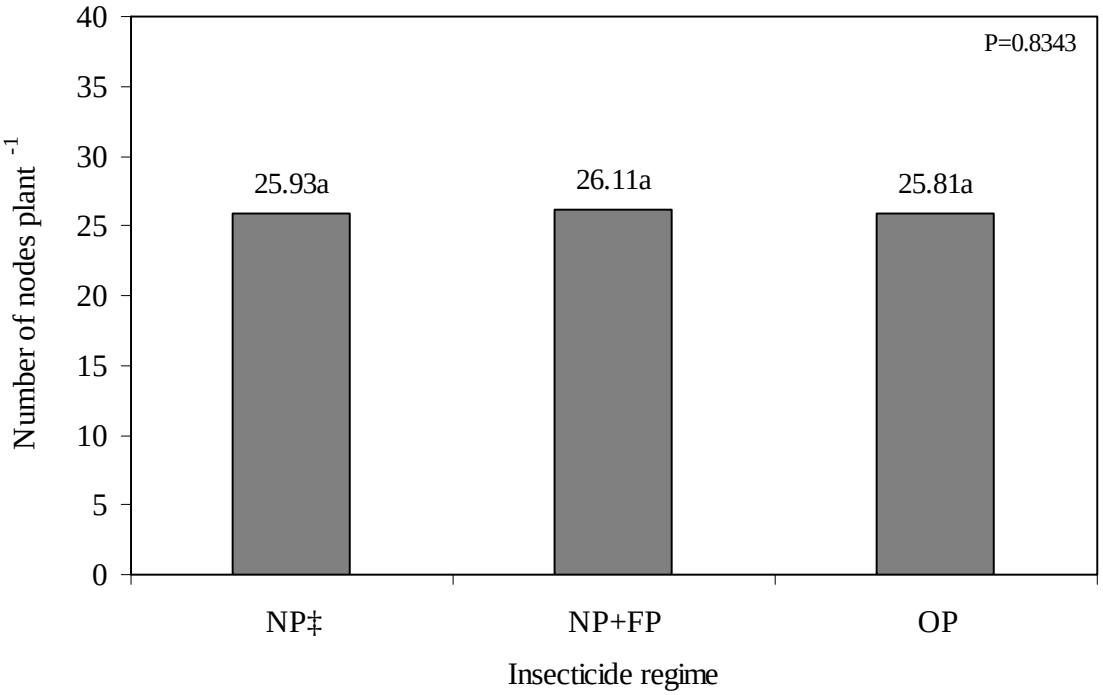

Fig. 51. Number of main-stem nodes combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

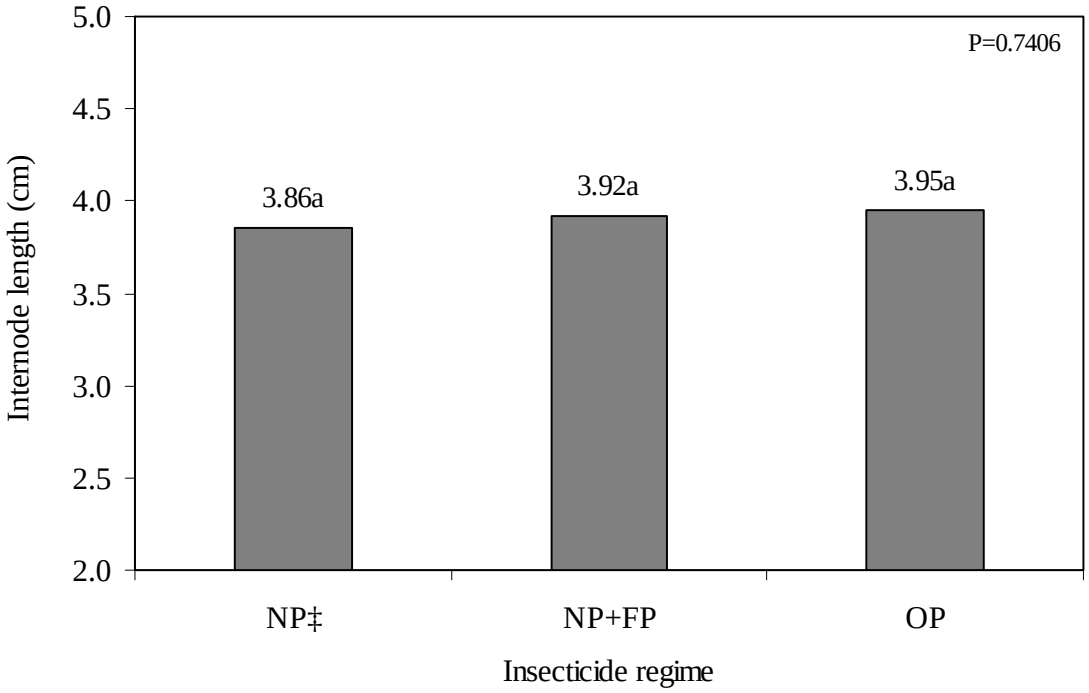

Fig. 52. Average internode length combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

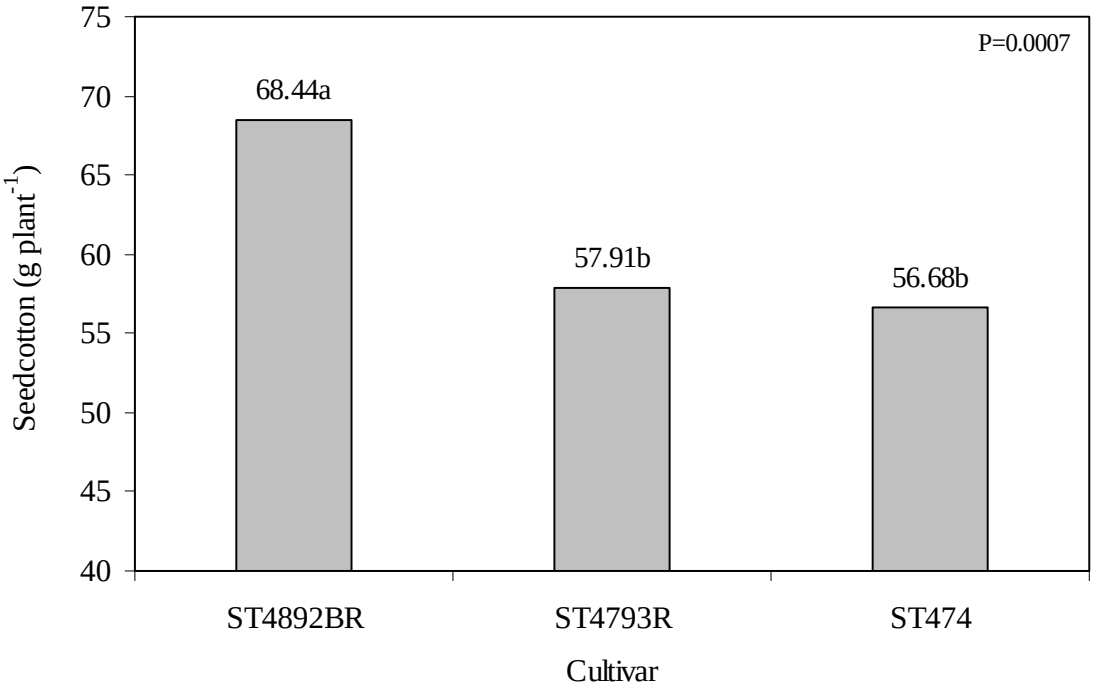

Fig. 53. Seedcotton yield per plant combined over years at harvest for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

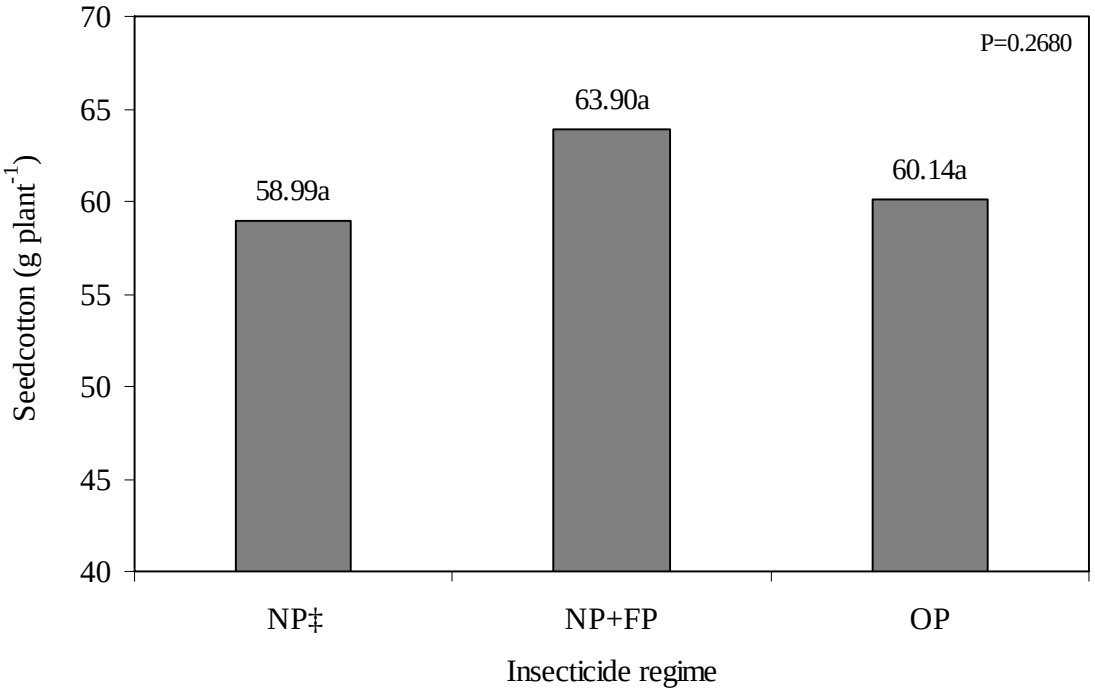

Fig. 54. Seedcotton yield per plant combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

statistic as an estimation of the population parameter (i.e. mean) and the required time and cost to achieve this degree of accuracy (Ott and Longnecker, 2001). This limitation in sample size could potentially explain the lack of significant differences for total seedcotton weight plant^{-1} of individual IR treatments acquired from box mapping compared to those obtained through field harvest. For example, the standard error of the seedcotton weight estimates for both cultivar and IR main effects was, on a relative basis, twice as high as that from the seedcotton yield analysis from the machine harvest. The box mapping results for the cultivars were different enough to generate a small probability value. However, less contrast in IR treatments consequently resulted in a non-significant probability estimate for that parameter. Regardless of a lack of statistical differences, the same recurring trend appears in total seedcotton weight per plant as was observed in lint yield and other parameters previously discussed.

The most important contributors to yield are boll number and boll size. At harvest, the 2001 and 2002 crop had similar number of total bolls per plant (Fig. 55). Though no statistical difference exists, the 2002 crop had a numerical increase of approximately 1.5 bolls plant^{-1}. In spite of the excellent compensatory qualities of cotton (Sadras, 1995), the primary contribution to the increase in 2002 yield was likely due to increased plant densities. However, the larger boll size observed for the 2002 crop contributed substantially to final yields. The average boll weight was approximately 0.6 g boll^{-1} greater than that of the 2001 crop (Fig. 56). A possible explanation for this increase could be that 2002 presented excellent growing conditions, in terms of rainfall distribution and temperatures, for cotton. Furthermore, the

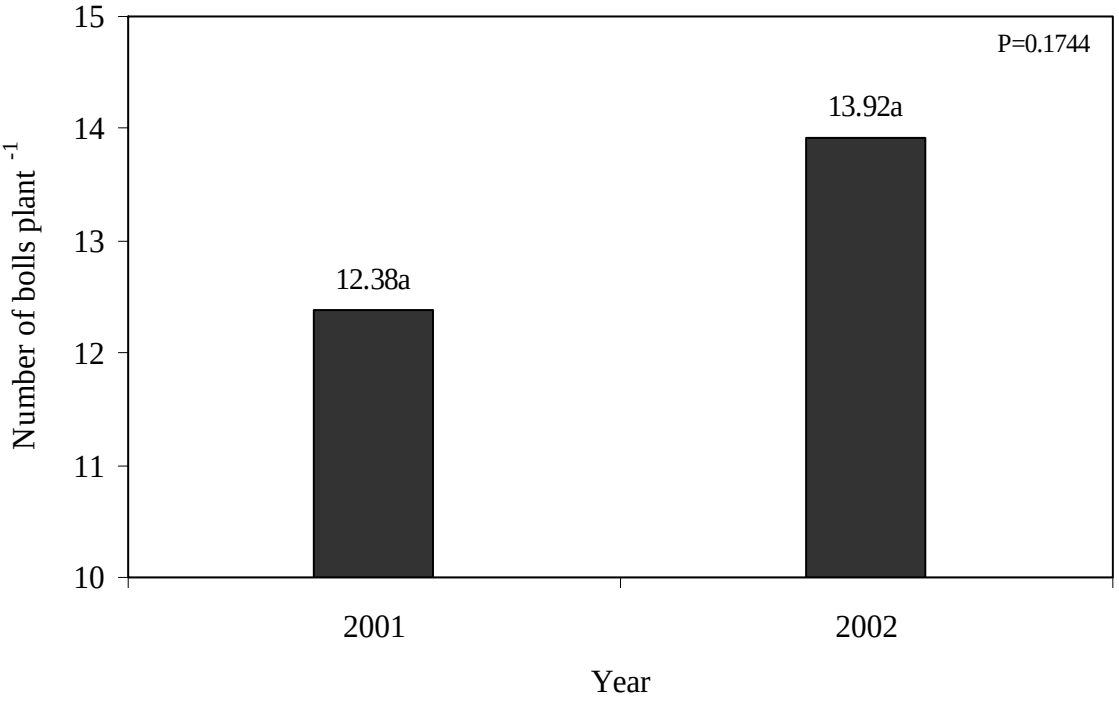

Fig. 55. Number of harvestable bolls per plant at harvest for 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

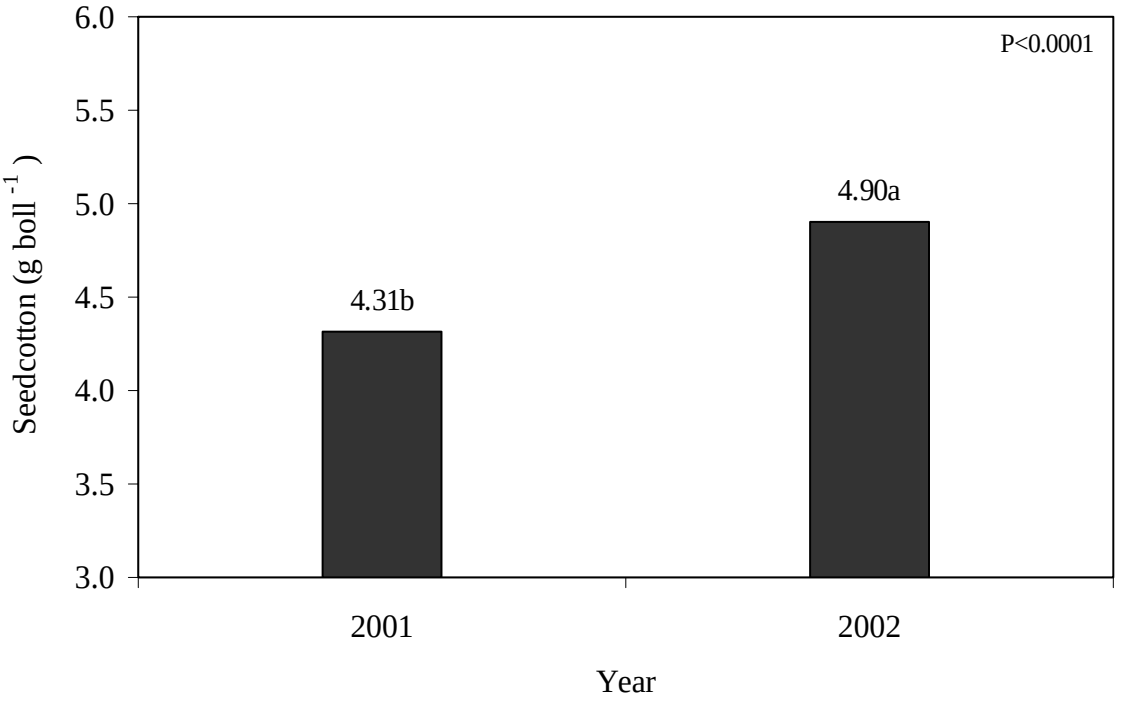

Fig. 56. Mean seedcotton weight per boll at harvest for 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

subsurface drip irrigation could have promoted increased rooting depth, subsequently resulting in more favorable moisture levels and increased nutrient uptake. This theory is supported by Phene (1999) who stated that subsurface drip irrigation has been shown to promote deeper crop rooting than surface irrigation in hybrid sweet corn (*Zea Mays* L., cv. Supersweet Jubilee). Phene (1999) stated that the root length densities of hybrid sweet corn grown under subsurface drip irrigation were greater from a depth of approximately 30 to 200 cm below the soil surface. In addition, he contended that a root system under subsurface drip irrigation usually will operate under a cooler constant temperature environment, thereby resulting in lower root respiration. In turn, he asserts that this causes an increase in net photosynthesis. He maintains that similar rooting patterns have been characterized for cotton and tomato, and in general, found that maximum root length density occurs at the depth of the water source, at least down to 60 cm. The yield increase for the 2002 crop is supported by the findings of Wilson et al. (1984) who revealed that converting to drip irrigation from furrow irrigation on sandy soils reduced water applications from about 170 cm to 90 cm and increased cotton yield by approximately 280.4 kg lint ha^{-1}. In another study with conditions more closely related to those of this study, Smith et al. (1991) compared a buried drip system, a low-energy precision application (LEPA) system, and a furrow system on a clay loam soil. They found that a yield increase of 616.8 kg lint ha^{-1} was observed for the drip system over the other two systems. The LEPA and furrow system produced equivalent yields.

The end-of-season box mapping data confirmed the numerical differences in boll number trends observed between cultivars at peak bloom. Those trends were enhanced

as the season progressed, resulting in statistical differences at harvest. The yield increase for ST4892BR can primarily be attributed to greater boll numbers. This cultivar produced approximately 1.5 more bolls per plant than ST4793R and ST474 (Fig. 57), which reflects the positive trend that was initially observed at peak bloom for ST4892BR in terms of numerical differences. It is apparent that ST4892BR continued to set more bolls as the season progressed. An additional contribution to the increased yield of ST4892BR was boll size. The mean weight per boll produced by ST4892BR was approximately 6% greater than that of ST4793R and ST474, with the three cultivars averaging 4.8, 4.6, and 4.5 g boll^{-1}, respectively (Fig. 58). Though peak bloom biomass partitioning did not reveal differences in boll size among cultivars, end-of-season mapping indicated that the larger boll size of ST4892BR was attributed to bolls set prior to, as well as after, peak bloom. Consequently, it can be argued that boll enlargement was consistent for all three cultivars at least until peak bloom. Following peak bloom, a point was reached where ST4793R and ST474 ceased boll enlargement while ST4892BR continued. These results indicate that the stacked-gene cultivar can produce higher yields than the Roundup Ready® and conventional counter parts through setting more and larger bolls.

The trend for total boll numbers of the IR treatments at peak bloom showed a numerical increase for NP+FP, which was maintained throughout the season. Box mapping at harvest revealed the primary constituent for the yield increase of NP+FP was boll numbers. Though no statistical differences were evident (P=0.1115), a numerical increase of approximately 1.1 bolls plant^{-1} for NP+FP was observed (Fig. 59).

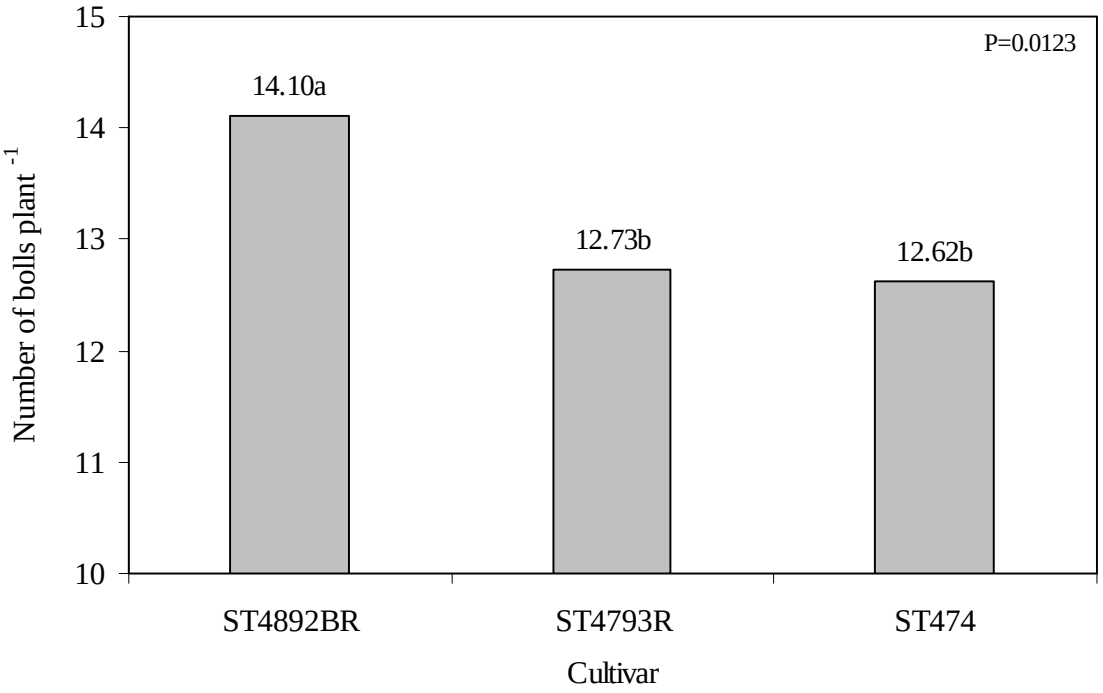

Fig. 57. Number of harvestable bolls per plant combined over years at harvest for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

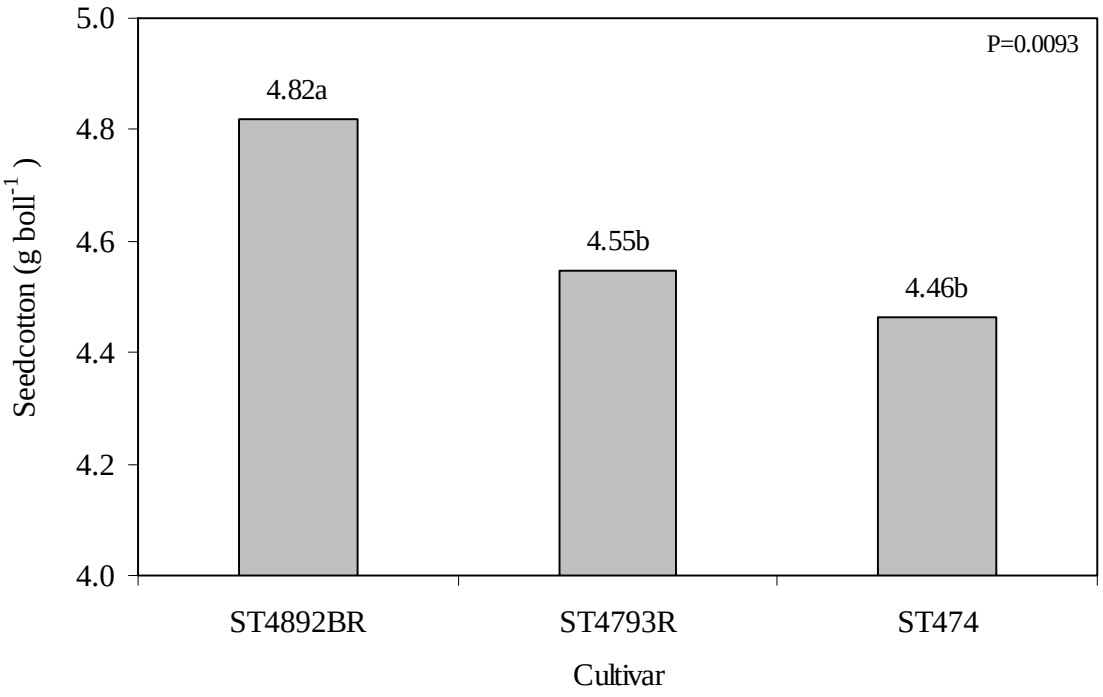

Fig. 58. Mean seedcotton weight per boll combined over years at harvest for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

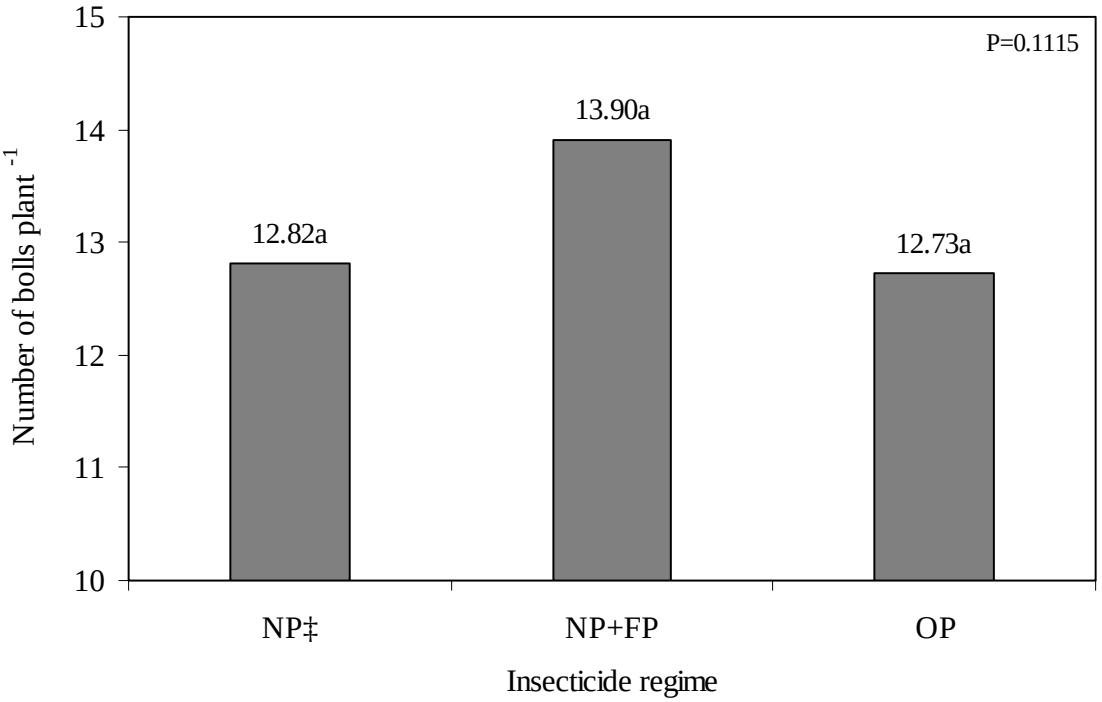

Fig. 59. Number of harvestable bolls per plant combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Treatments of OP did not increase boll numbers over NP. The IR treatments had little effect on boll size. Mean boll weights for NP, NP+FP, and OP were 4.6, 4.6, and 4.7 g $boll^{-1}$, respectively (Fig. 60). Treatments of OP numerically increased mean weight by 0.1 g $boll^{-1}$; however, this slight gain did not impact overall yield.

The primary contribution to the increase in total boll numbers for the 2002 crop came from first and second position bolls. The 2002 crop had approximately 1.8 and 1.1 more first and second position bolls, respectively, than the 2001 crop (Fig. 61). The number of third position bolls was not different between years.

The number of first position bolls was dependent upon cultivar. The increase in total bolls per plant for ST4892BR was primarily due to an increase in the number of first position bolls. ST4892BR had approximately one more first position boll than the other two cultivars (Fig. 62). The number of second and third position bolls was not different among the three cultivars.

Application of IR treatments did not affect the number of first position bolls. The NP, NP+FP, and OP treatments averaged 6.6, 6.6, and 6.4 first position bolls per plant, respectively (Fig. 63). The increase in total bolls for the NP+FP treatment at harvest was primarily due to an increase in the number of second position bolls. The addition of foliar phosphorus added approximately one more boll per plant than treatment with NP alone. Second position boll numbers for the OP treatment was not different from that of NP or NP+FP. The number of third position bolls was not affected by any IR treatment. Further examination of boll distribution throughout the plant revealed that the primary source of the increase in second position bolls for the NP+FP

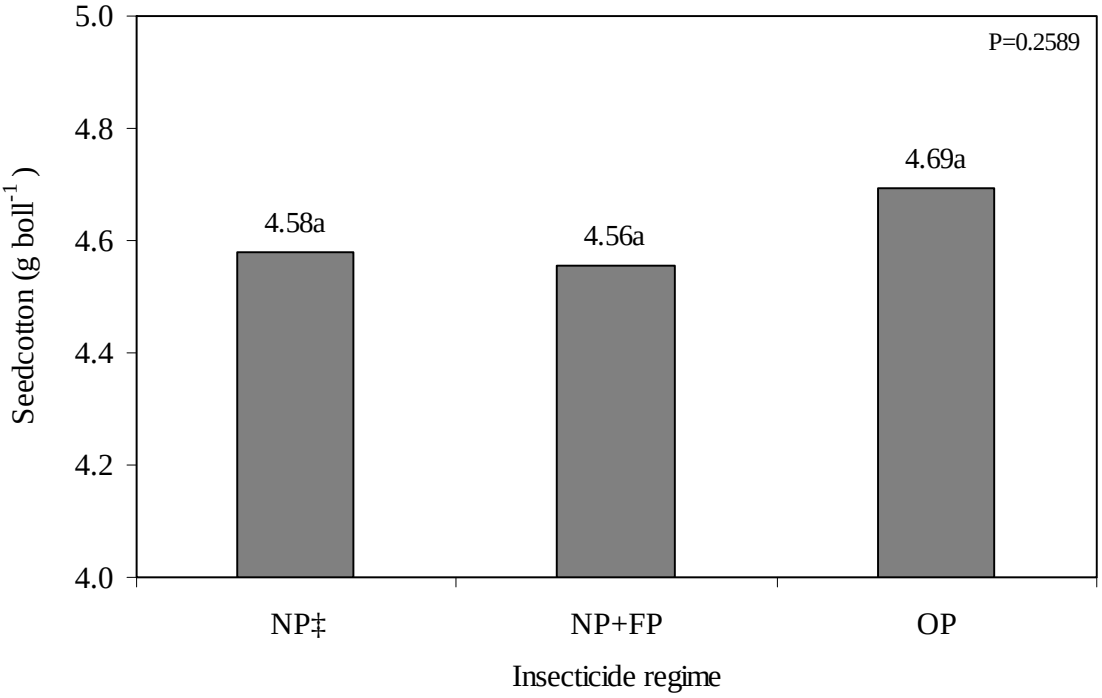

Fig. 60. Mean seedcotton weight per boll combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

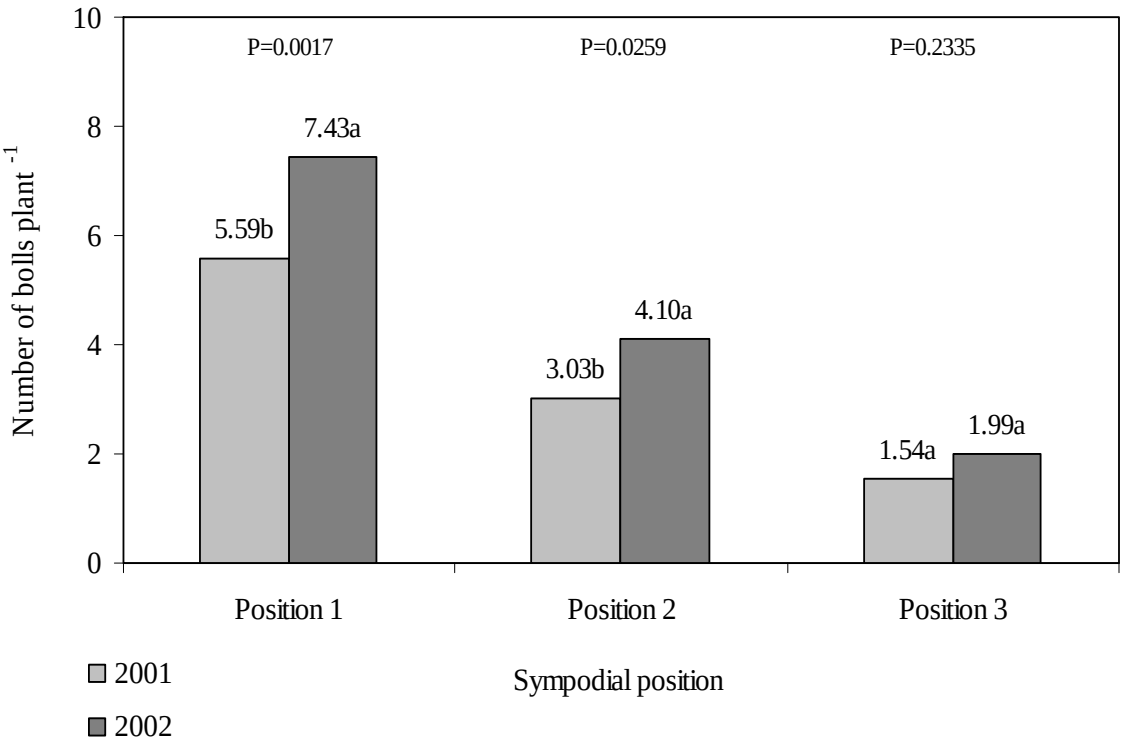

Fig. 61. Number of harvestable bolls located at fruiting positions 1, 2, and 3 per plant at harvest for the 2001 and 2002 field studies. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

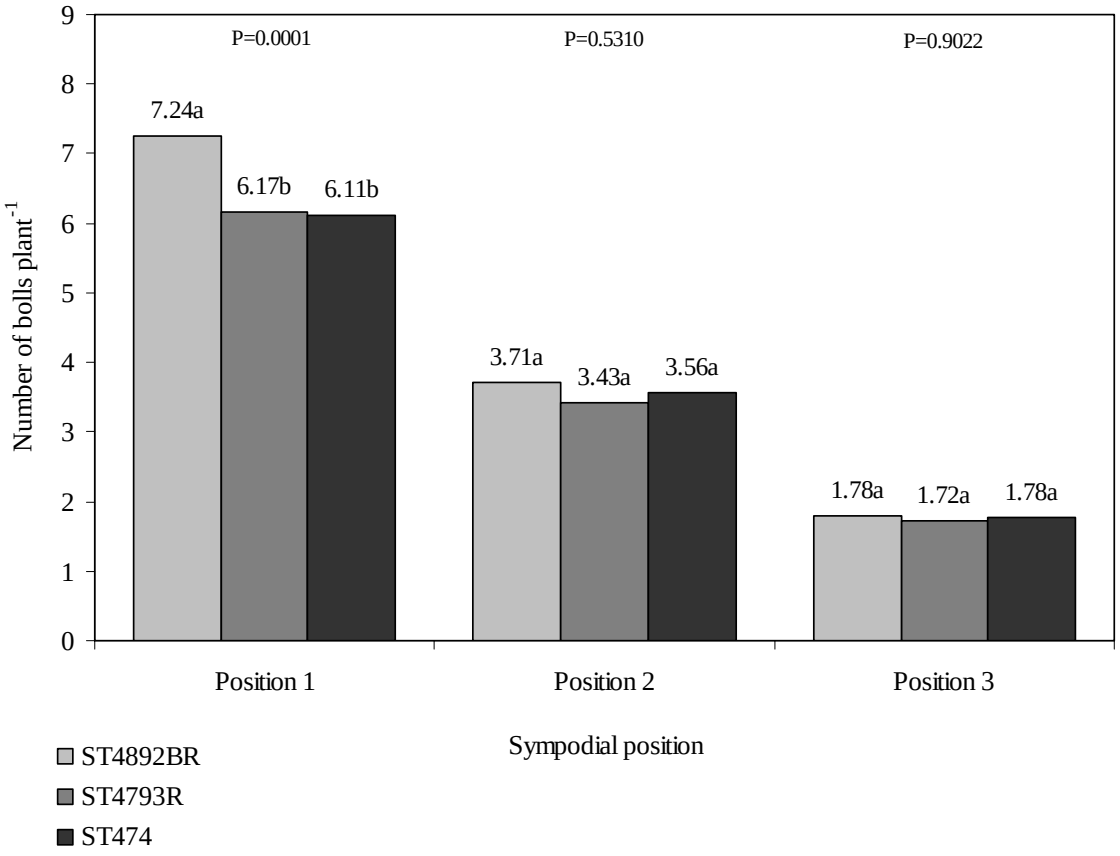

Fig. 62. Number of harvestable bolls located at fruiting positions 1, 2, and 3 per plant combined over years at harvest for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

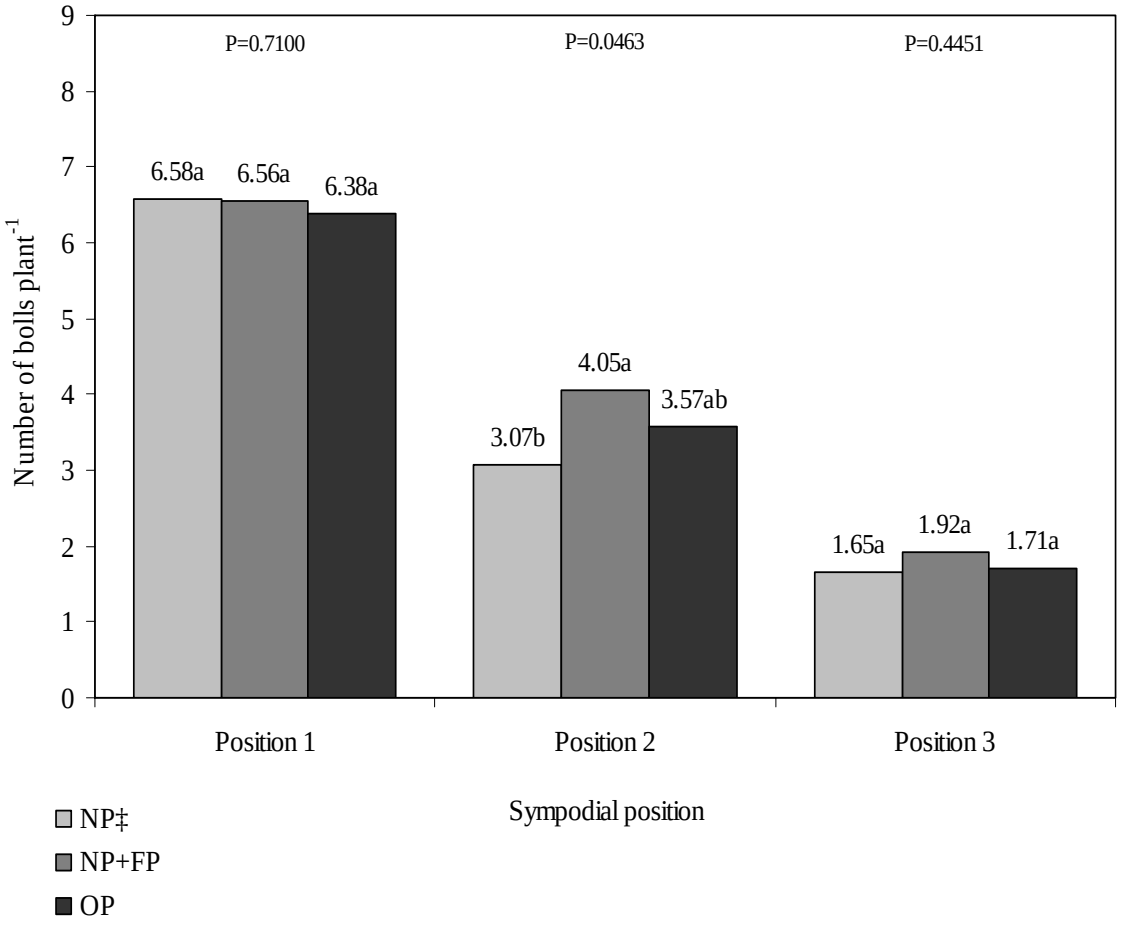

Fig. 63. Number of harvestable bolls located at fruiting positions 1, 2, and 3 per plant combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

treatment was predominantly within sympodial range 6 through 10 (Fig. 64). The addition of FP increased (P=0.0533) second position bolls by 0.6 bolls plant^{-1} over the NP treatment. The remaining 0.4 bolls that account for the total increase in second position bolls for NP+FP (Fig. 63) are accounted for in numerical increases distributed throughout sympodia 16 through 25 (Data not shown). The reason for the increase in second position bolls for the NP+FP treatment is not clearly understood. However, a possible explanation is that the small amount of FP provided during boll fill may have compensated for nutrient requirements not met through soil uptake and/or alleviated demand from competition for nutrients with first position fruit. Crozier (2004) stated that under conditions of heavy fruiting, the plant directs most of its resources into boll development rather than into new root and shoot growth. He also indicates that root uptake can be less than required to meet peak nutrient demands. Furthermore, Taiz and Zeiger (1998) contend that foliar nutrition can reduce the lag time between application and uptake by the plant, which could be important during a phase of rapid growth. This explanation, however, does not account for the lack of yield response for the OP treatment which had P levels similar to NP+FP. In addition, no visual P deficiencies were observed in any of the treatments during the boll-fill period. Though this explanation could be plausible, it cannot be confirmed by the data from this study.

The evaluation of fruit distribution at harvest is vital to understanding the contribution of individual components to final yield. Bolls set lower on the plant are typically larger and potentially contribute more to yield than those set higher on the plant (Kerby et al., 1987; Gerik et al., 1989; Jenkins et al., 1990a; Boquet et al., 1993; Boquet

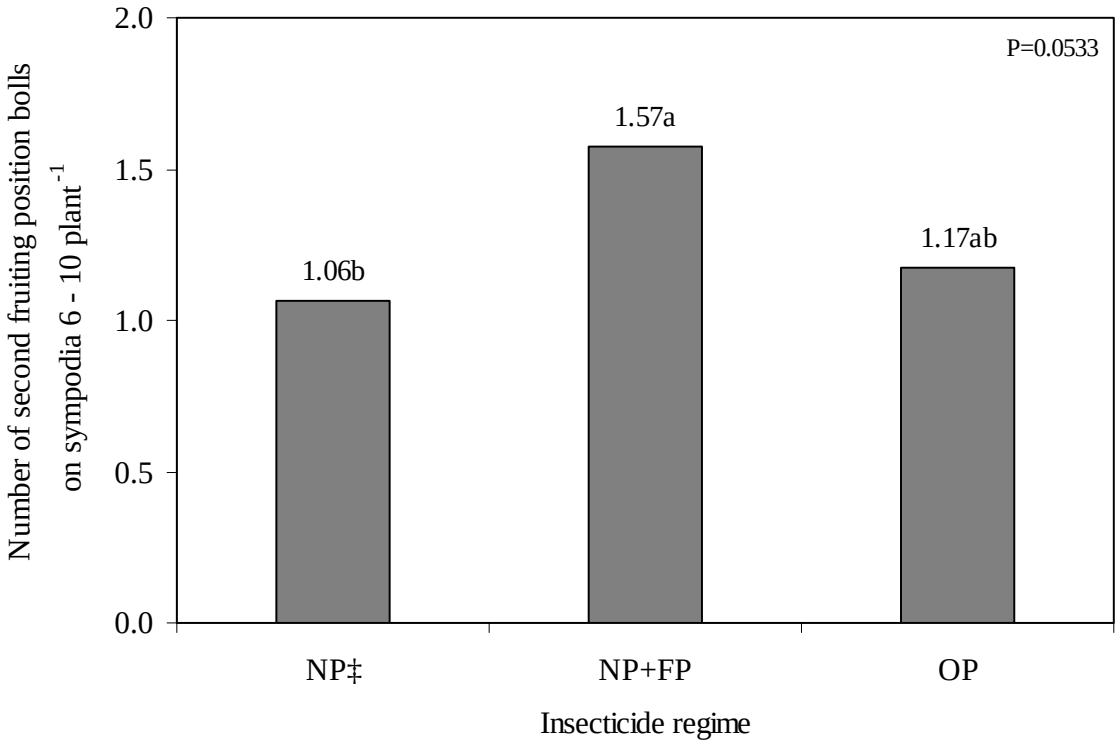

Fig. 64. Number of harvestable bolls located at the second fruiting position throughout sympodia 6 through 10 combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

et al., 1994; Kerby and Hake, 1996). Total boll numbers were not different between 2001 and 2002 for sympodial ranges 3 through 5 and 6 through 10 (Fig. 65). The predominant contribution to the numerical increase in total boll numbers for 2002 was from sympodia 11 and above. The 2002 crop had consistently more bolls than 2001 in this region of plant architecture. The substantial increase in lint for the top crop in 2002 further reflects the sensitivity of cotton to environmental limitations. As discussed earlier, this increase may also reflect more favorable growing conditions under subsurface drip irrigation and its impact on boll load.

Cultivar and IR treatments had little effect on the number of bolls on sympodia 3 through 5, 11 through 15, and 16 through 20 (Figs. 66 and 67, respectively). The sympodial range that contributed most to the yield increase for ST4892BR was 6 through 10 (Fig. 66). ST4892BR produced approximately 0.8 and 1.2 more bolls in this range than ST4793R and ST474, respectively. The conventional cultivar produced more bolls ($P=0.0518$) than ST4793R on sympodia 21 through 25. ST4892BR did not differ in boll numbers from the other two cultivars.

The IR treatments had little effect on boll numbers in sympodial range 6 through 10 (Fig. 67). However, the positive numerical trend for boll numbers follows the documented yield increase observed for NP+FP. Application of IR treatments affected boll numbers within sympodial range 16 through 25. The data suggests that additional FP increased boll numbers over the NP treatment in this region of the plant architecture. However, the individual contribution of this sympodial range to final yield is limited (Hake et al., 1996b). Though boll numbers are relatively small in this sympodial range,

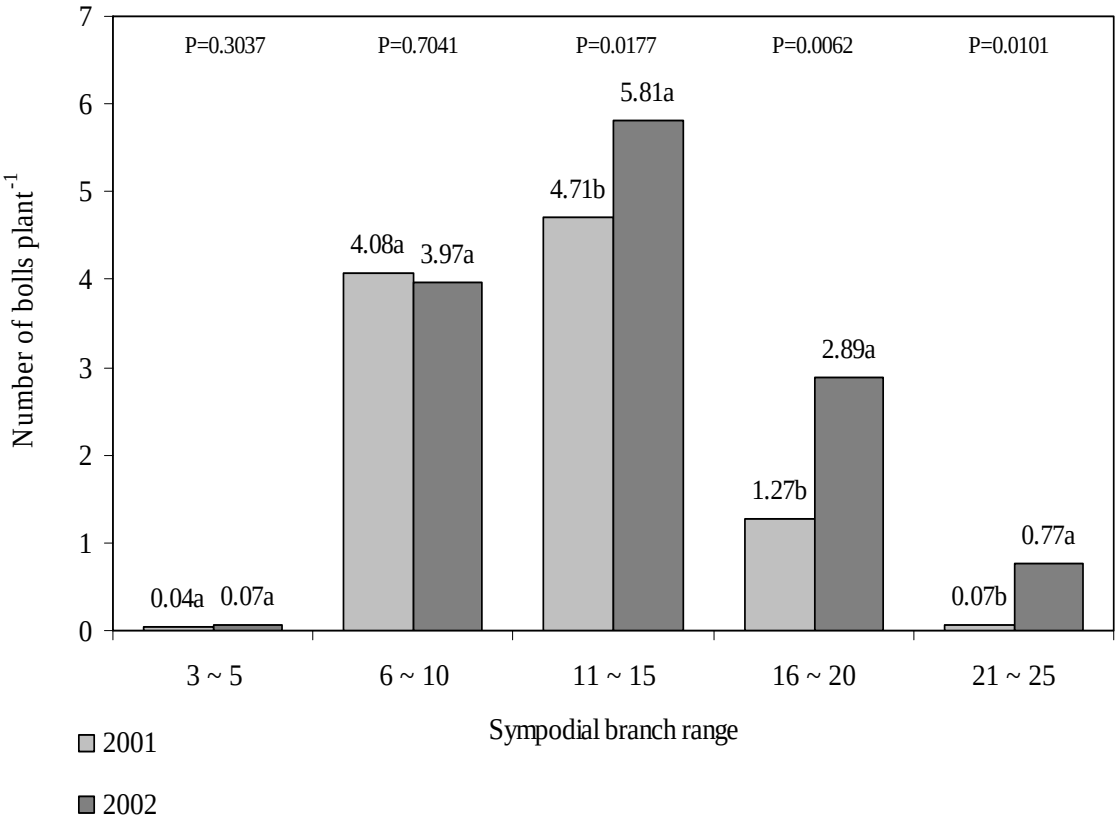

Fig. 65. Number of harvestable bolls per plant separated according to distribution on sympodia 3 through 25 at harvest for the 2001 and 2002 field studies. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure.

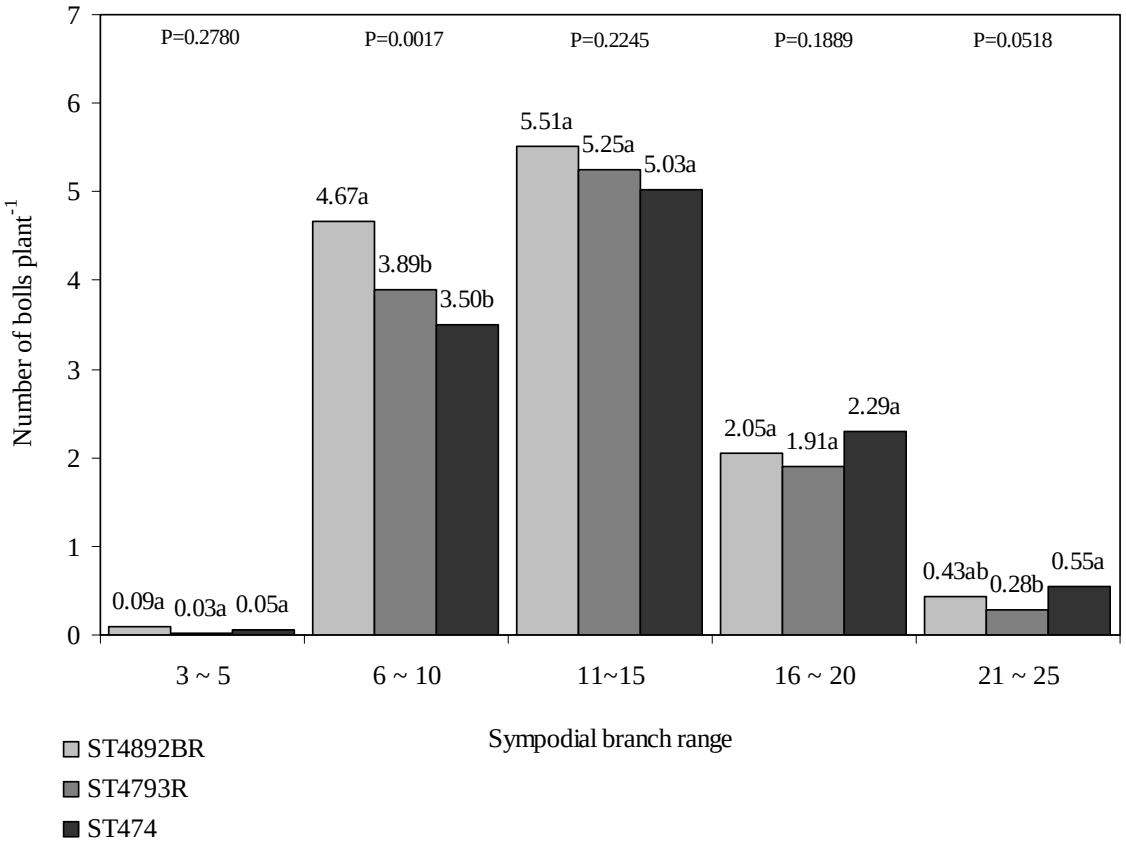

Fig. 66. Number of harvestable bolls per plant separated according to distribution on sympodia 3 through 25 combined over years at harvest for the three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

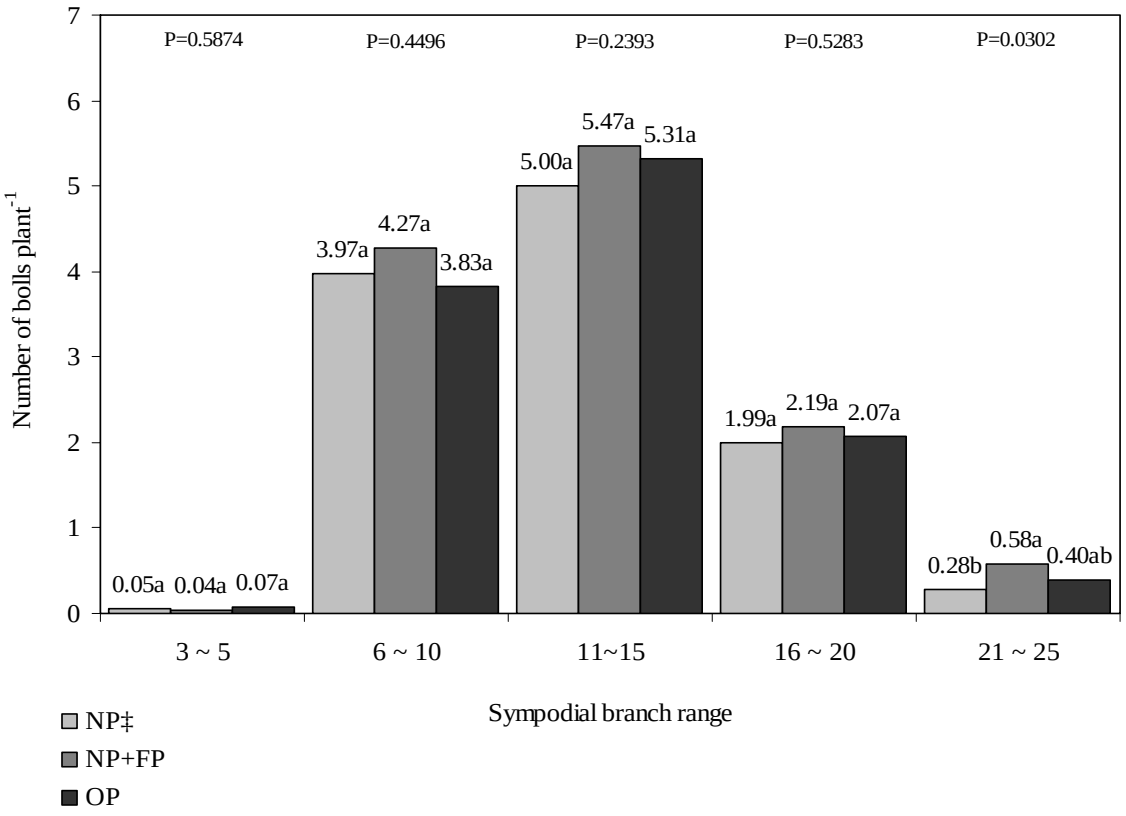

Fig. 67. Number of harvestable bolls per plant separated according to distribution on sympodia 3 through 25 combined over years at harvest for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

the recognizable positive trend for the NP+FP treatment throughout the plant ultimately culminated in a favorable yield response.

The largest contribution to yield for cultivar and IR main effects was attributed to sympodial range 11 through 15, with a substantial amount also coming from sympodia 6 through 10. As a percentage of final yield, sympodia 6 through 10 and 11 through 15 accounted for approximately 37 and 47%, respectively, for cultivar and IR main effects (Figs. 68 and 69, respectively). Approximately 14% of final yield was contributed by sympodia 16 through 20 for both cultivar and IR treatments.

Cultivar did not affect percent yield contribution of sympodia 3 through 15 (Fig. 68). The conventional cultivar contributed approximately 3 and 2% more yield from sympodia 16 through 20 and sympodia 21 through 25, respectively, compared to the other two cultivars. The two transgenic cultivars were not different across all sympodial ranges.

IR treatments had little effect on percent yield contribution of sympodia 3 through 20 (Fig. 69). However, a significant IR treatment effect was observed for sympodia 21 through 25. Addition of FP resulted in 1.5 times the yield contribution from sympodia 21 through 25 than NP alone, which confirms the observation for increased boll numbers for NP+FP in this sympodial range. The OP treatment did not significantly affect the distribution of seedcotton as a percentage of final yield for any sympodial range.

Box mapping provided effective insight about the components contributing to yield differences between the two years. The predominant factor that contributed to

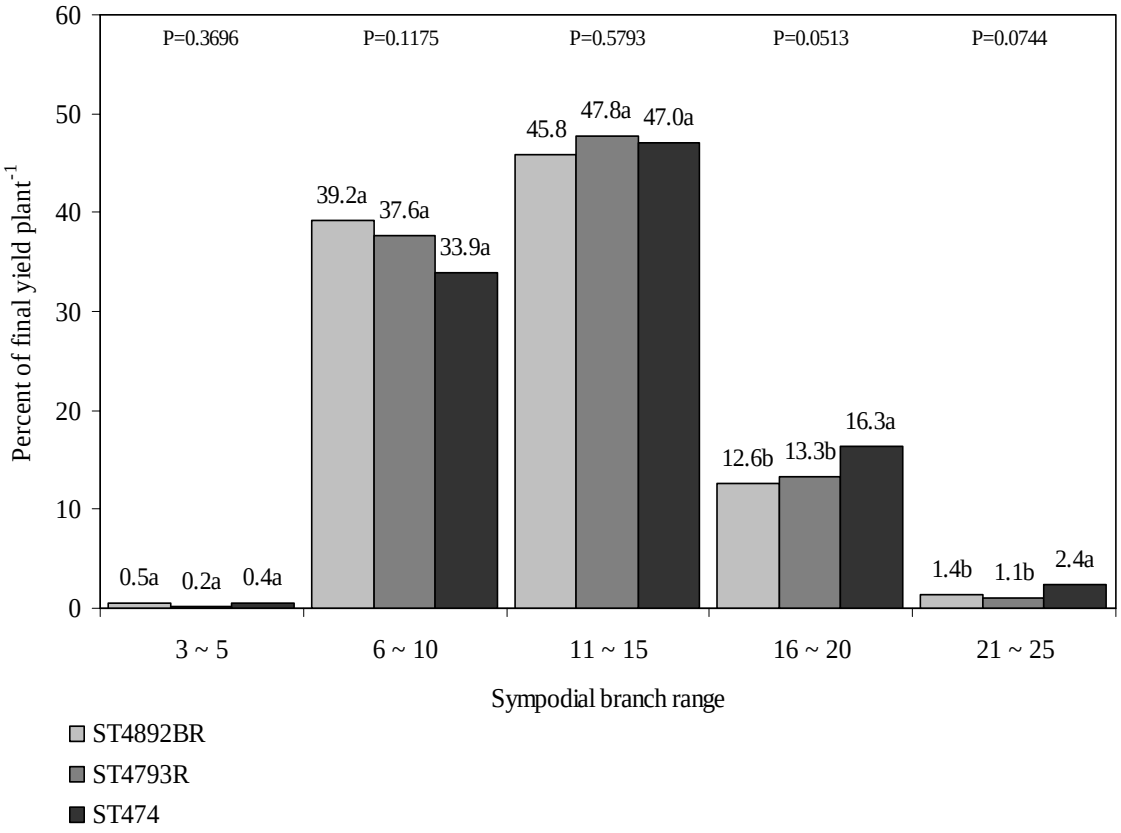

Fig. 68. Seedcotton contribution of sympodial ranges as a percentage of final yield combined over years for three cotton cultivars in the field study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

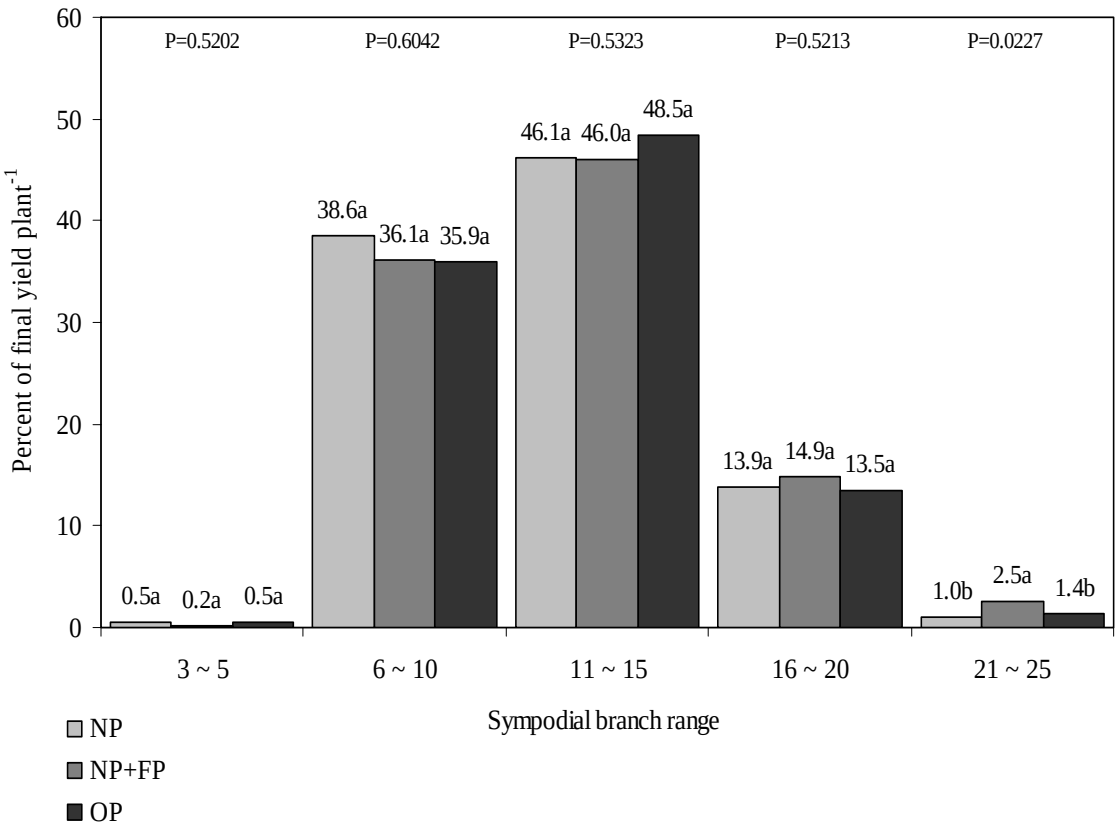

Fig. 69. Seedcotton contribution of sympodial ranges as a percentage of final yield combined over years for insecticide regime (IR) treatments in the field study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

higher yields in 2002 was larger boll size. Furthermore, the numerical increase of 1.5 bolls plant^{-1} for the 2002 crop contributed to the yield increase. In addition, the end-of-season mapping confirmed many of the trends observed at peak bloom for cultivar and IR main effects. The stacked-gene transgenic cultivar out-yielded its Roundup Ready® and conventional counterparts through increased boll size and total boll numbers. Applications of OP insecticides did not offer any benefits over use of NP. Addition of FP tended to increase total boll numbers, especially second position bolls. This increase is reflected in greater final yields for NP+FP than for NP. These results support those of Lancaster and Savatli (1965) who reported yield increases with foliar applied P. However, the application rate used in their study was 8.72 kg P ha^{-1}, a much greater amount than was used in this study. In addition, they found that a sufficient soil application of P could negate any benefits of foliar applied P. While there is evidence that foliar applications can increase yield, there is some question as to whether the amounts used in this study corroborate those results. The application of OP insecticides did not influence any of the fruiting distribution or position characteristics studied. No significant cultivar by IR treatment interactions were detected for the data presented in the field study section of this document, which suggests that the three cultivars responded similarly to all levels of IR treatment applications.

GREENHOUSE STUDY

In addition to examining cultivar and IR treatments under field conditions, these variables were also tested on cotton grown under greenhouse conditions. Many benefits are associated with conducting a trial in a controlled environment including improved pest, fertility, and water management. However, the study of larger crops in this environment presents limitations, especially in the magnitude of sample size for data collection. This reduced sample size could lead to a high degree of variability in the data resulting in a failure to detect significant differences. The primary source of variability in greenhouse studies is probably due to the inherent differences between plants within a genetic line, which was observed during the greenhouse study. This phenomenon was expected and efforts were taken to maximize the number of observational units in order to increase sample size. In spite of attempts to increase the sample size, the number of replicates was still small relative to the field trial. Even with this potential limitation, the greenhouse study provides further opportunity to investigate the selected parameters on cotton under more intensive observation.

Yield

The study was harvested 146 DAP and seedcotton was collected and weighed on a per plant basis. No differences in seedcotton yield plant^{-1} were observed for cultivar and IR main effects. The seedcotton yields for ST4892BR, ST4793R, and ST474 were 126.6, 124.8, and 125.6 g plant^{-1}, respectively (Fig. 70). The NP, NP+FP, and OP treatments yielded 125.7, 126.2, and 125.1 g plant^{-1} (Fig. 71).

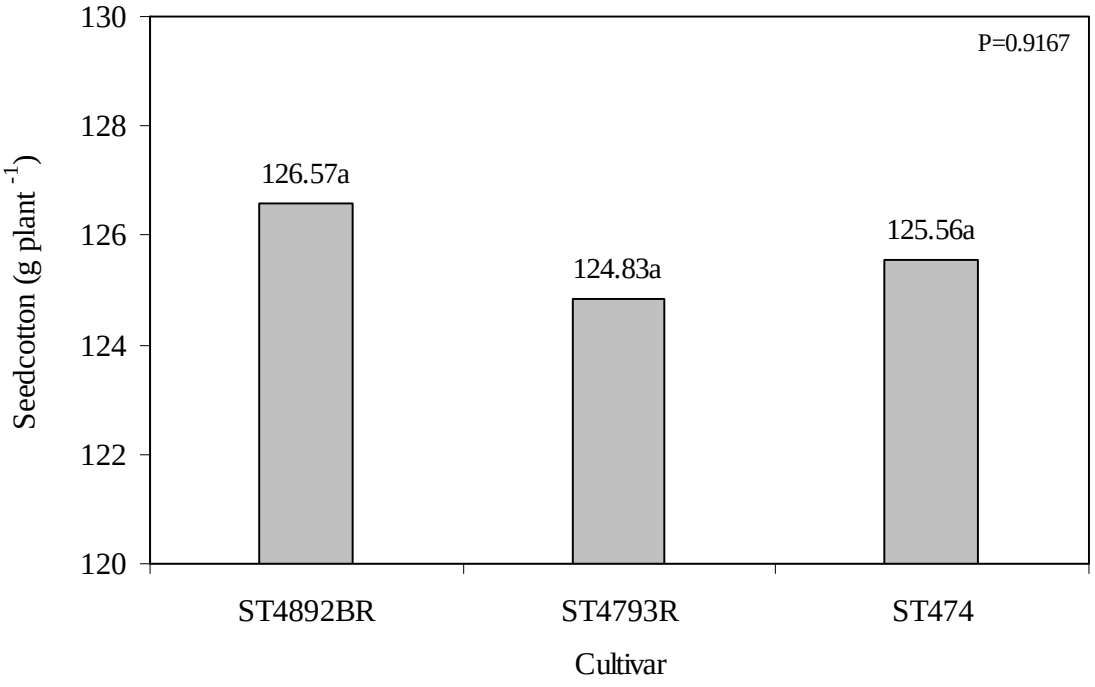

Fig. 70. Seedcotton yield per plant for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

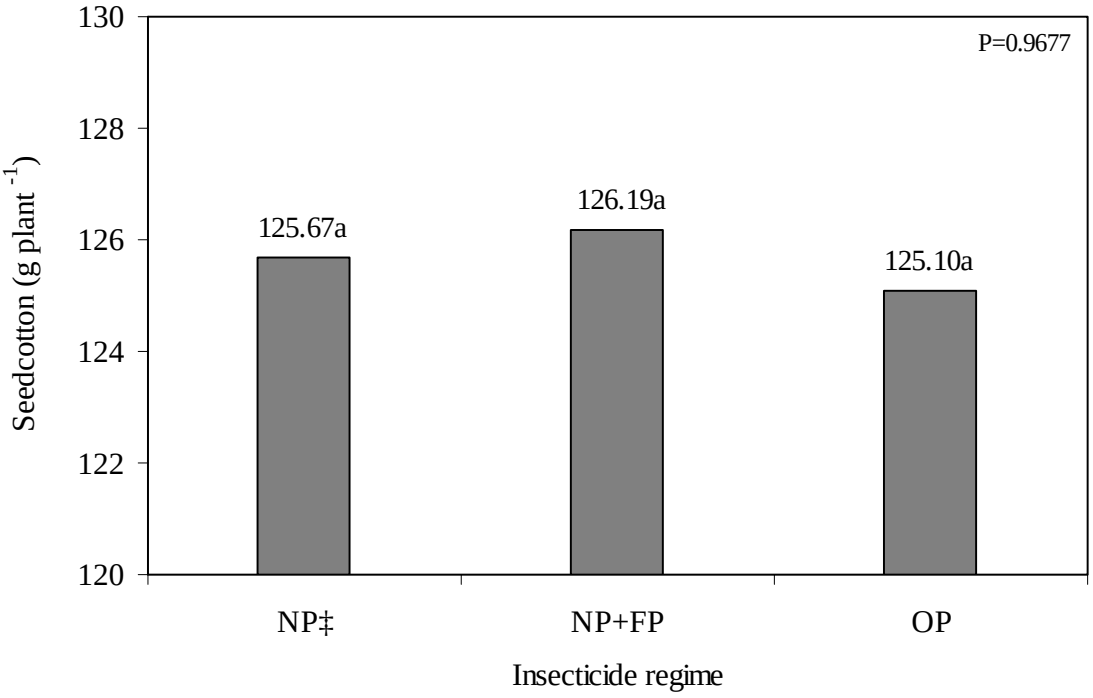

Fig. 71. Seedcotton weight per plant for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Residual analysis of yield data revealed a substantial amount of variability. Consequently, it is reasonable to postulate that the absence of statistical differences in yield could be attributed to this variability.

Leaf Tissue Nutrient Analysis

Foliar P was applied to the plots designated as the NP+FP treatment in the field study as 12-48-08. To eliminate extraneous variables in the greenhouse study, liquid phosphorus fertilizer, in the form of 0-30-0, was acquired from Growth Products, Ltd. (White Plains, NY). Calculations for the required P_2O_5 amounts equivalent to the concurrent OP treatments were performed in the same manner as the procedure used in the field study. The leaf samples for this tissue analysis were collected after all seven IR treatments were applied.

Leaf tissue analyses for nutrient content failed to provide concrete evidence about the influence on leaf P levels for the IR treatments. The concentration of P in the tissue for NP, NP+FP, and OP treatments was 8.52, 8.65, and 8.75 g P kg^{-1}, respectively, and were not significantly different, although the OP treatment had the largest numerical increase in leaf P (Fig. 72). The total kg P applied from the seven IR applications amounted to 0.3042 kg P ha^{-1} (Table 9).

The leaf P concentrations between the two cultivars were not significantly different. The P concentration in the leaf tissue of ST4892BR and ST474 were 8.55 and 8.73 g P kg^{-1}, respectively (Fig. 73). The magnitude of difference between cultivars, approximately 0.17 g P kg^{-1}, was greater than the difference of 0.13 g P kg^{-1} observed for the NP and NP+FP treatments.

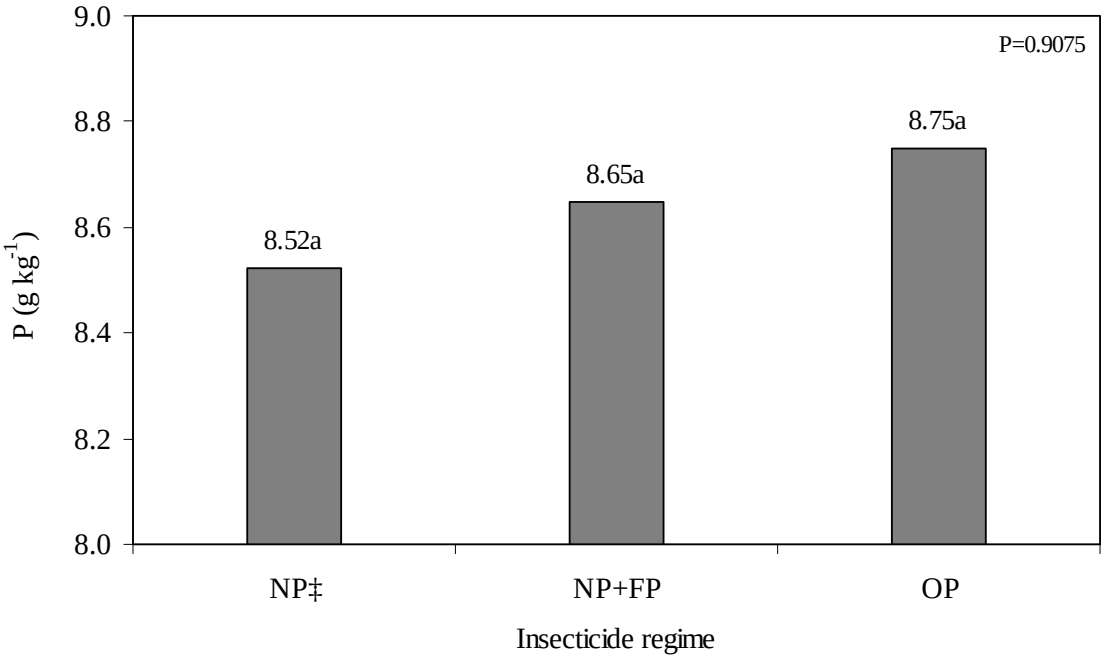

Fig. 72. Phosphorus (P) concentration in leaf tissue for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Table 9. Amount of phosphorus (P) applied through individual NP+FP foliar treatments for seven insecticide regime (IR) treatment applications in the greenhouse study.

IR Application Number	L 0-30-0 ha^{-1}	kg P_2O_5 ha^{-1}	kg P ha^{-1}
1	0.1796	0.0627	0.0274
2	0.1796	0.0627	0.0274
3	0.1796	0.0627	0.0274
4	0.1796	0.0627	0.0274
5	0.3605	0.1258	0.0549
6	0.4585	0.1600	0.0699
7	0.4585	0.1600	0.0699
Total	1.9959	0.6966	0.3042

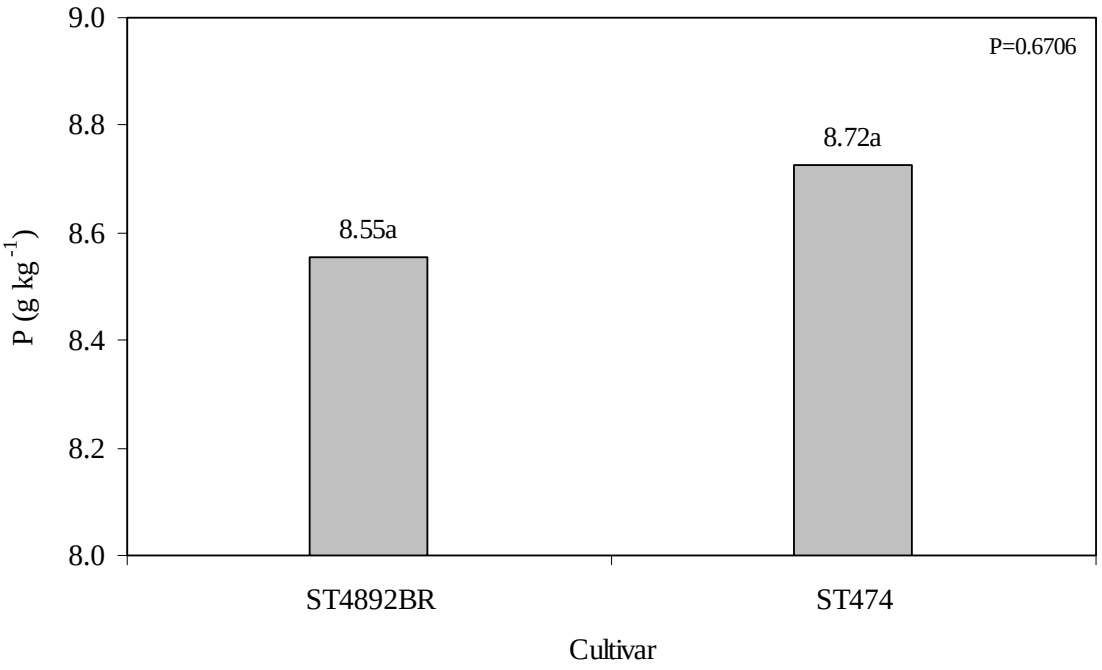

Fig. 73. Phosphorus (P) concentration in leaf tissue for two cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

Leaf P concentrations in our greenhouse study (8.52 to 8.75 g kg^{-1}) were substantially greater than leaf P concentrations (3 to 6.4 g kg^{-1}) reported in other work (Sabbe and Zelinski, 1990; Bednarz et al., 1999). However, leaf P concentrations in the field study (2.49 to 3.12 g kg^{-1}) were consistent with those reported in the work of these authors.

A unique finding revealed by comparing greenhouse and field leaf P data was the magnitude of difference between leaf P concentrations between the two studies. Leaf P concentrations in the greenhouse study were approximately three times greater than that of the field trial. Mullins and Burmester (1990) reported that, with exception to seed, P concentrations in the cotton plant tended to decrease with age. They also reported that P distribution within the plant averaged 11.7% shoots, 19.5% leaves, 16% burs, and 52.8% seed. Bassett et al. (1970), while examining dry matter accumulation and nutrient uptake in irrigated cotton, reported evidence of considerable translocation of nutrients from the vegetative tissue into the bolls in late season. It is unlikely that sampling leaf tissue 35 days earlier for the greenhouse study compared to the field study sampling date could have influenced leaf P concentrations to the extent observed in the greenhouse study, even though some nutrient translocation has been reported to occur.

Under field conditions, soil application of nutrients was not provided after the side-dress application of N prior to first bloom in our study. Consequently, if uptake of nutrients did not meet the requirements of the developing fruit, some nutrients would have been transported from other non-reproductive plant parts, including the leaves. Conversely, in the greenhouse study, this possibility was minimized because of the

frequent application of soil fertilizer to the pots. The excellent growing conditions of the greenhouse environment resulted in vigorous plant growth creating a high nutrient demand. To avoid plant nutrient stress, frequent soil-applied fertilizer applications were made during the fruit-set and boll-fill period. Therefore, the difference in leaf P concentrations observed may partially be attributed to different fertilizer regimes followed for the two studies.

Results from the field study regarding cultivar and IR main effects and their influence on leaf P levels were more conclusive than the findings for the greenhouse study. The high variability in the greenhouse data, combined with the absence of significant mean differences, negated circumstantial evidence that foliar P and OP insecticides affected leaf P concentrations under greenhouse conditions. Based on the data analysis, it could not be ascertained if plants acquired P from OP insecticides in the greenhouse. Furthermore, the greenhouse study did not provide evidence of cultivar differential response to FP treatments on leaf P concentrations.

Plant Growth Parameters

Growth measurements were made periodically during the season to determine cultivar differences and influence of IR treatments on cotton under greenhouse conditions. These measurements also allowed for comparison of cotton behavioral response to field and greenhouse environments.

Cotton grown in this study reached maximum height at approximately 100 DAP, with only a slight increase in height thereafter until harvest. Cultivar had little effect on plant heights during the growing season. ANCOVA was used to determine if the slopes

for height modeled over time of each cultivar were different. Height trends for cultivars from 38 DAP until harvest (146 DAP) gave slopes that were equal (P=0.0915) throughout the growing season (Fig. 74). Furthermore, with the exception of cutout, height means were not different at any individual point at which measurements were obtained during the season. Height measurements acquired three days after cutout indicated that both transgenic cultivars were significantly taller than the conventional cultivar (Fig. 75). However, this height contrast for cultivars was not present at harvest.

Application of IR treatments had little effect on plant height at any point during the growing season. Plant heights recorded three days after cutout for the IR treatments ranged between 144.2 and 147.6 cm (Fig. 76). ANCOVA was performed on height data recorded from 38 to 79 DAP and confirmed the absence (P=0.7352) of IR treatment effects on plant height from 38 to 79 DAP (Fig. 77).

Differences in number of nodes were detected between cultivars at cutout. ST474 had approximately 0.5 more nodes plant^{-1} than ST4892BR (Fig. 78). ST4793R was not different from the other two cultivars. However these differences in nodal number were not realized at harvest. Application of IR treatments did not affect the number of nodes at any point during the growing season (Data not shown).

Cotton grown in this study achieved maximum internode length at approximately 83 DAP (one week post-cutout). Fig. 79 illustrates average internode length trends for the three cotton cultivars. The ANCOVA procedure did not detect differences in the slope of average internode lengths between the three cultivars. However, during the growing season, ST474 generally had a smaller average internode length than the other

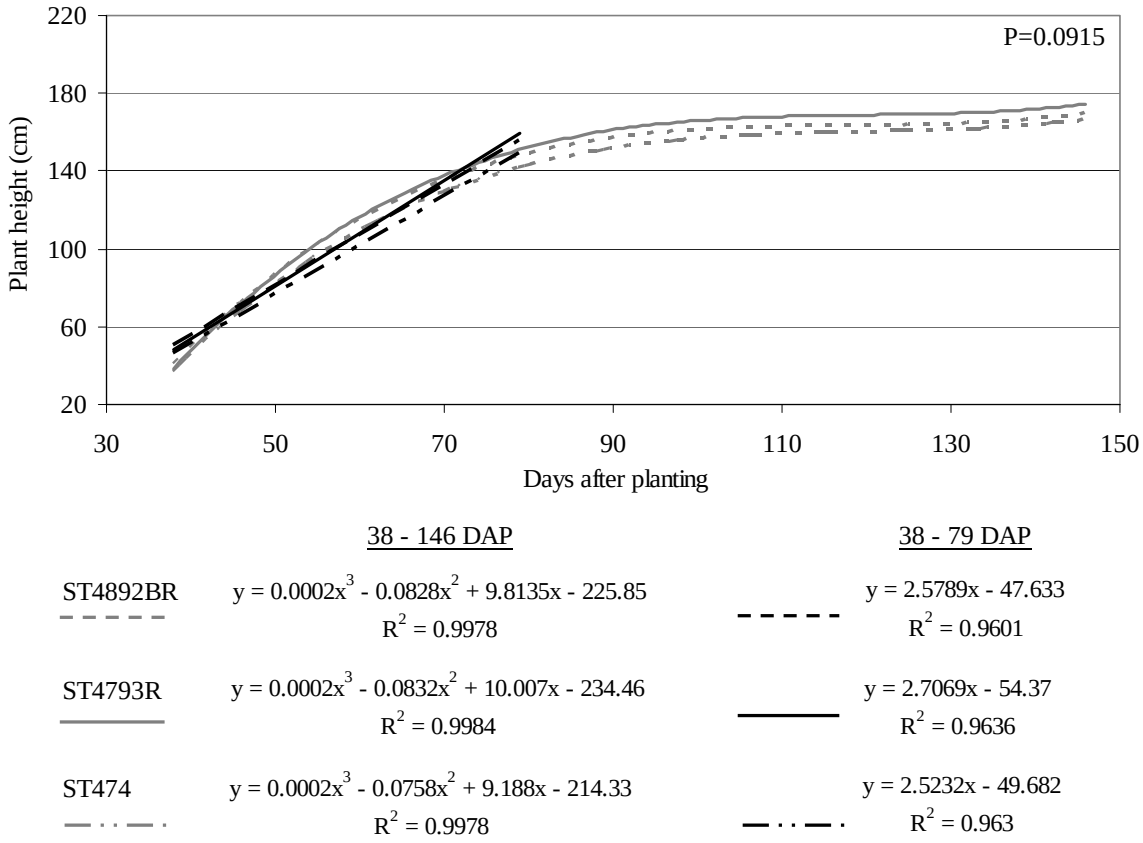

Fig. 74. Height trends for three cotton cultivars from 38 DAP until harvest (146 DAP) in the greenhouse study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines (38 to 79 DAP) are statistically different at $P<0.05$ according to the analysis of covariance procedure.

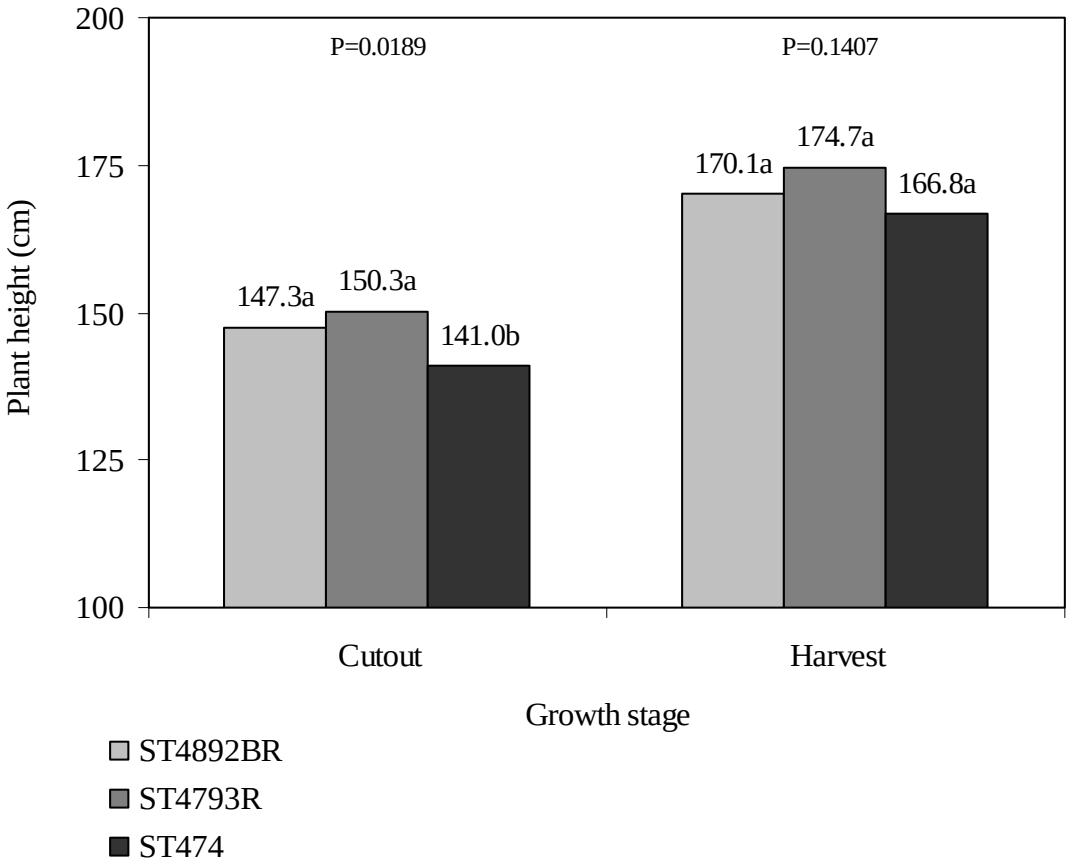

Fig. 75. Plant height at cotton cutout and harvest for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

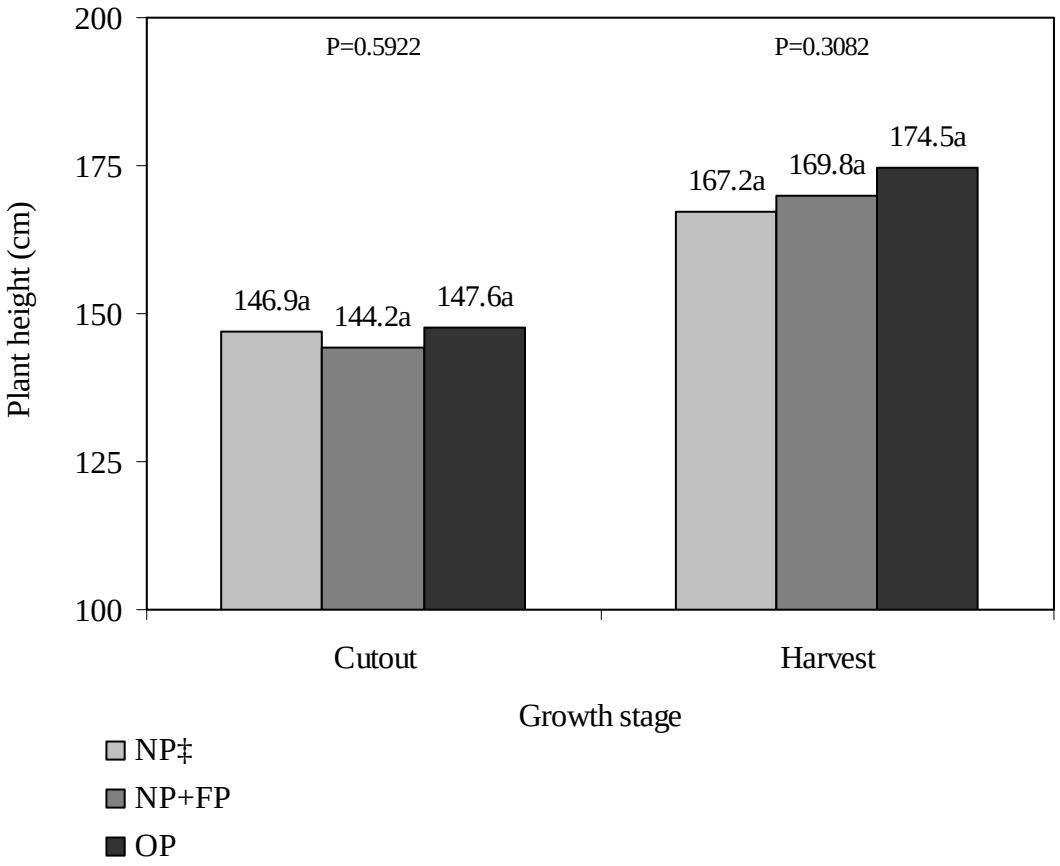

Fig. 76. Plant height at cotton cutout and harvest for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

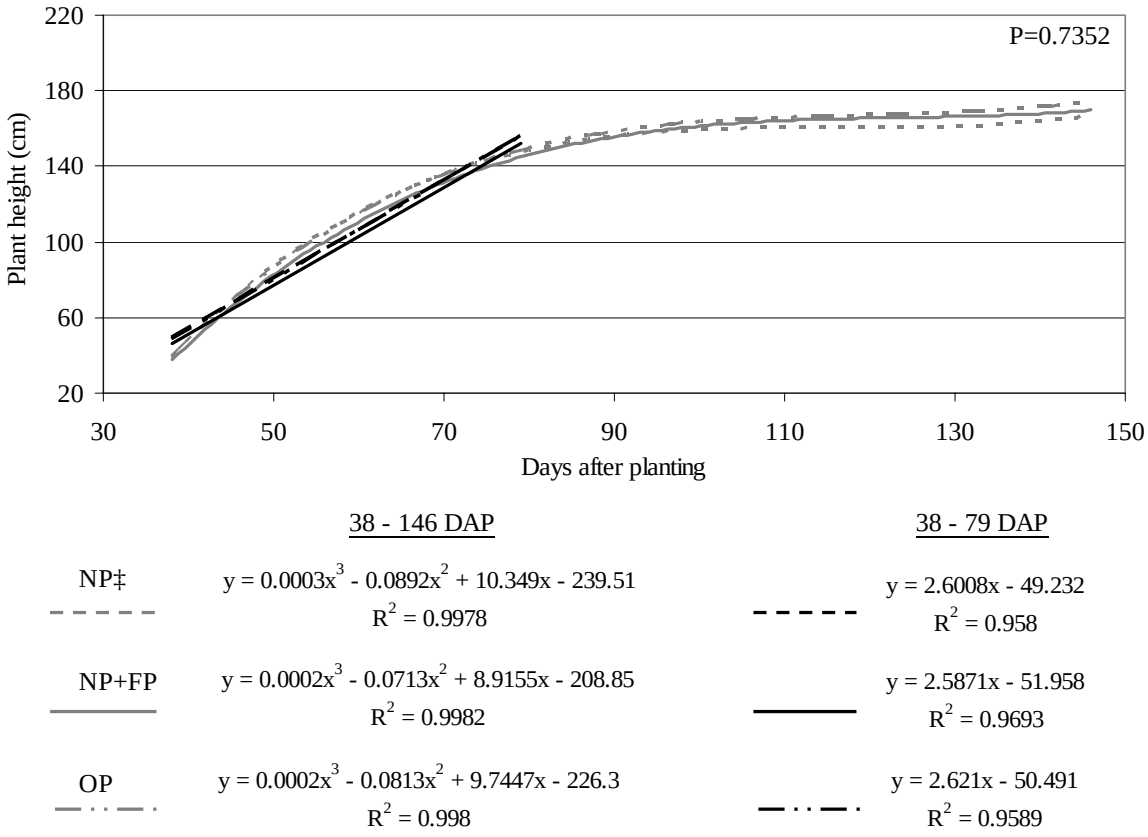

Fig. 77. Height trends for insecticide regime (IR) treatments from 38 DAP until harvest (146 DAP) in the greenhouse study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines (38 to 79 DAP) are statistically different at $P<0.05$ according to the analysis of covariance procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

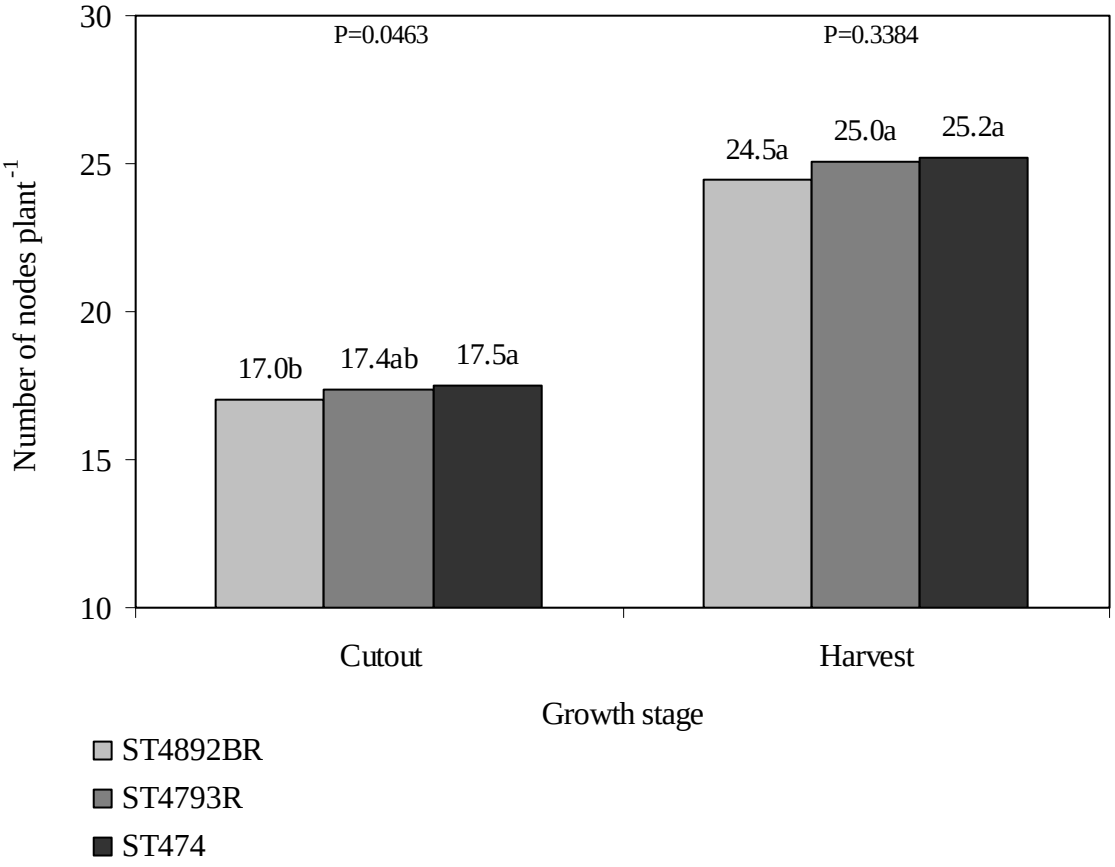

Fig. 78. Number of main-stem nodes at cotton cutout and harvest for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

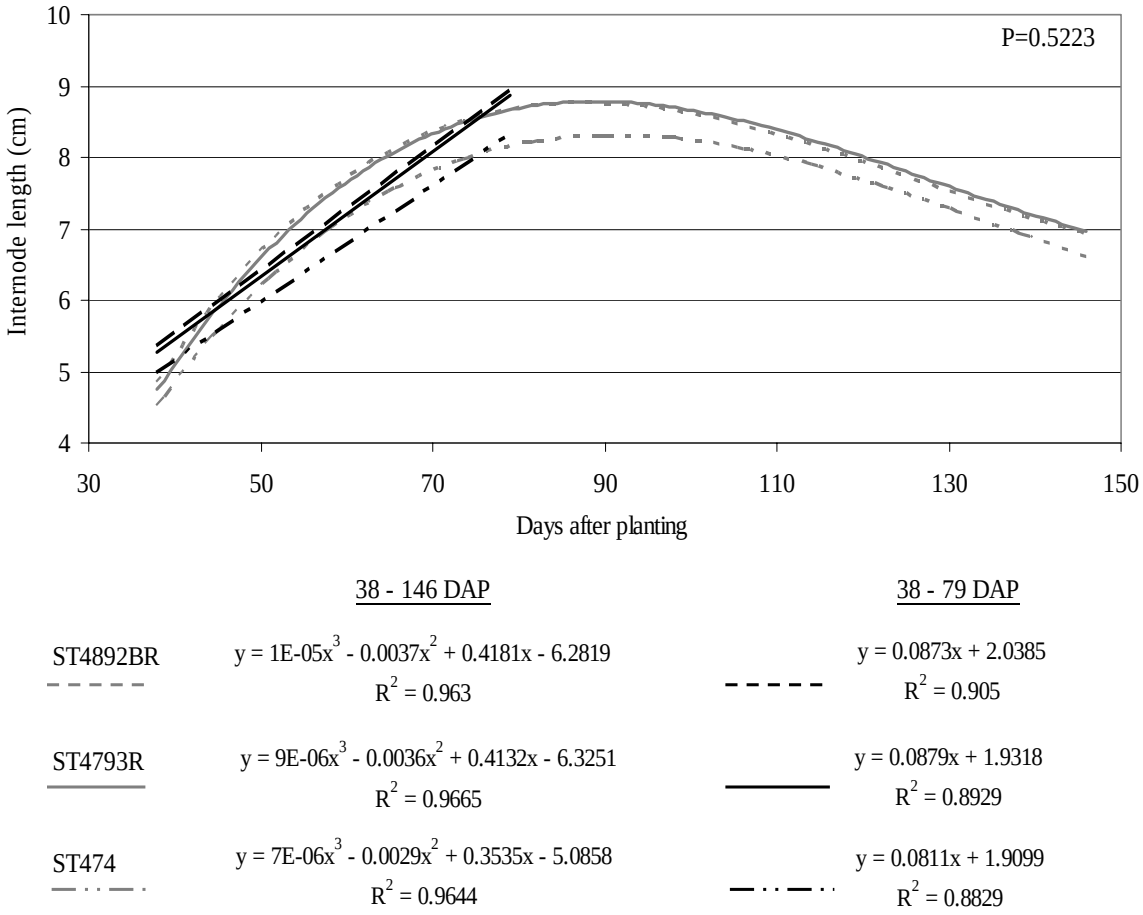

Fig. 79. Average internode length trends for three cotton cultivars from 38 DAP until harvest (146 DAP) in the greenhouse study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines (38 to 79 DAP) are statistically different at $P<0.05$ according to the analysis of covariance procedure.

two cultivars. This observation is confirmed by evaluating this parameter at cutout and harvest. At both cutout and harvest, ST474 had significantly smaller internode length than the other cultivars (Fig. 80).

Application of IR treatments had minimal effect on average internode length at any point during the season, which was expected based on the lack of response of plant height and number of nodes to the IR treatments. The test for equality of slopes among the IR treatments revealed unequal slopes (P=0.0364) (Fig. 81). The NP treatment had a greater slope than the NP+FP and OP treatments, suggesting that treatments containing P slightly affected plant vigor. Lancaster and Savatli (1965) found, in a preliminary experiment of foliar P applications, that spray solutions of monoammonium phosphate containing 2% percent P_2O_5 and solutions of orthophosphoric acid containing 0.5 % P_2O_5 caused noticeable burning of cotton leaves, which could affect plant vigor. In the greenhouse experiment, spray solutions of phosphoric acid used on the NP+FP treatments had percentages of P_2O_5 considerably lower than those reported by Lancaster and Savatli (1965), with ranges of 0.06 to 0.15 % P_2O_5 for the NP+FP treatments used in our study. Therefore, the source of variation in slopes for average internode length trends of IR treatments is not clearly understood. Peak internode length was observed approximately 83 DAP and begins to decline after 90 DAP. Fruit growth has a higher priority for carbohydrates than does vegetative growth (Kerby and Hake, 1996). Coincidentally, the observed peak in internode length corresponds in proximity to the timing of plant cutout, and the shift in carbohydrate allocation that occurs at this time.

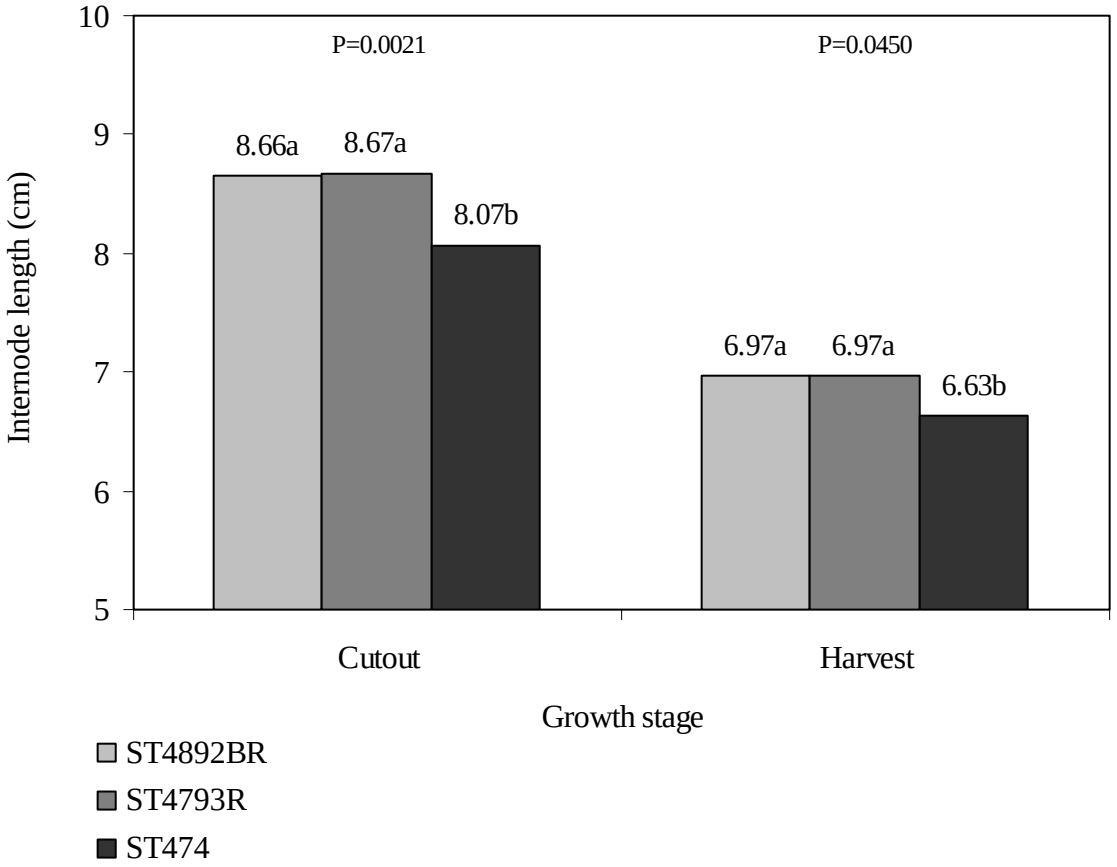

Fig. 80. Average internode length at cotton cutout and harvest for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

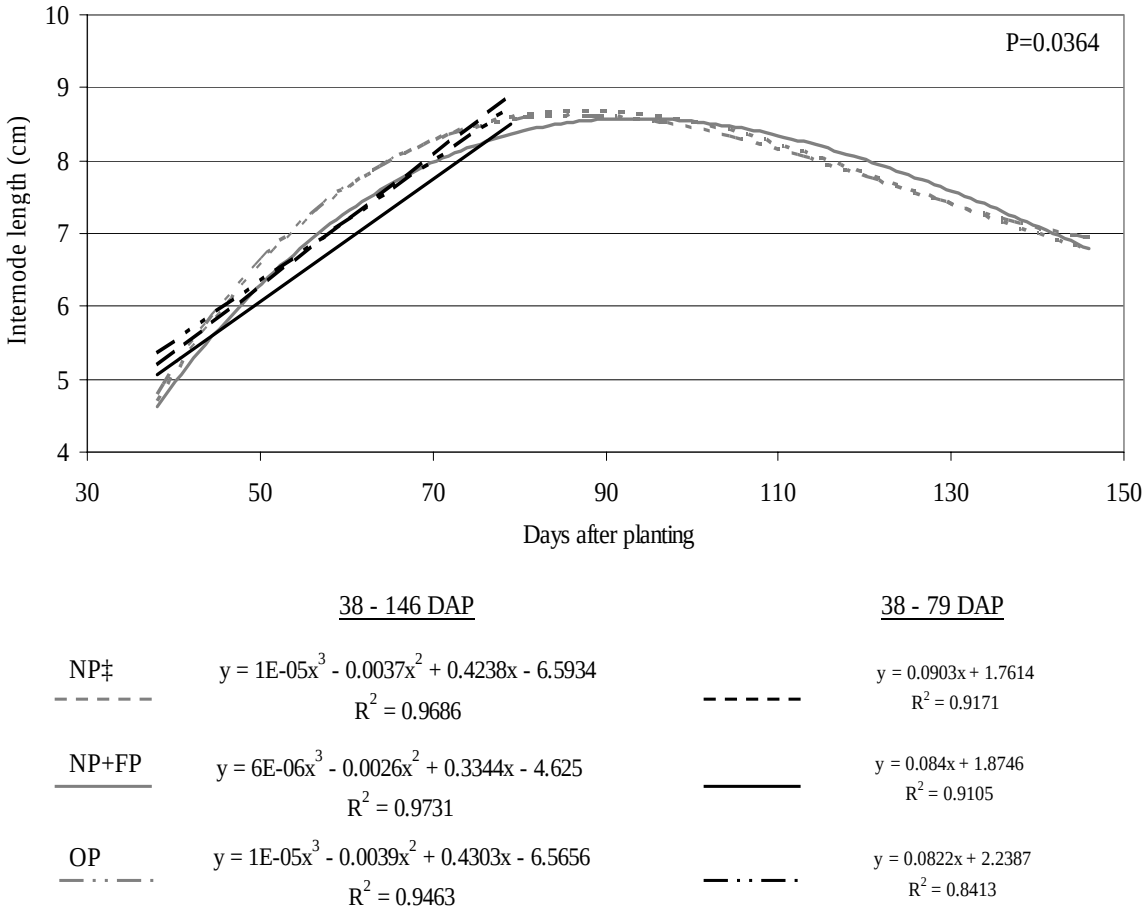

Fig. 81. Average internode length trends for insecticide regime (IR) treatments from 38 DAP until harvest (146 DAP) in the greenhouse study. The P-value displayed is associated with the test for equality of slopes. The slopes for the regression lines (38 to 79 DAP) are statistically different at $P<0.05$ according to the analysis of covariance procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

Cotton cutout in the greenhouse study was reached at approximately 76 DAP. Neither cultivar nor IR main effects influenced the timing of cotton cutout. The most interesting finding regarding this parameter was the difference between the cutout dates for cotton grown under field and greenhouse conditions. Cutout occurred approximately 19 days earlier in the greenhouse study. Investigation of greenhouse growing conditions provided insight into this occurrence. In general, the daily DD60s during the trial were consistently greater than those for the field study (Fig. 82). Furthermore, this trend resulted in a substantial increase in cumulative DD60s compared to the field study (Fig. 83). In both the field and greenhouse studies, it took approximately 1700 heat units to reach cutout. However, the rapid accumulation of heat units in the greenhouse environment resulted in the plants reaching cutout 19 days earlier. The data regarding heat unit accumulation in the greenhouse environment helps explain growth differences observed in greenhouse cotton compared to that grown in a field situation. Plants under greenhouse conditions achieved substantially greater height than those under field conditions. Plant heights ranged from 70 to 80 cm taller in the greenhouse. Mepiquat chloride was used in both field and greenhouse experiments to control plant height (Appendices A and B, respectively). Furthermore, plants in the greenhouse had approximately 2.5 more nodes than those in the field study. The average internode length was approximately two times greater in cotton grown in the greenhouse. These characteristic growth differences can be attributed to factors inherent to greenhouse conditions such as lack of plant competition, optimal water and fertility management, quality of light, and absence of stresses from unfavorable weather conditions and pests.

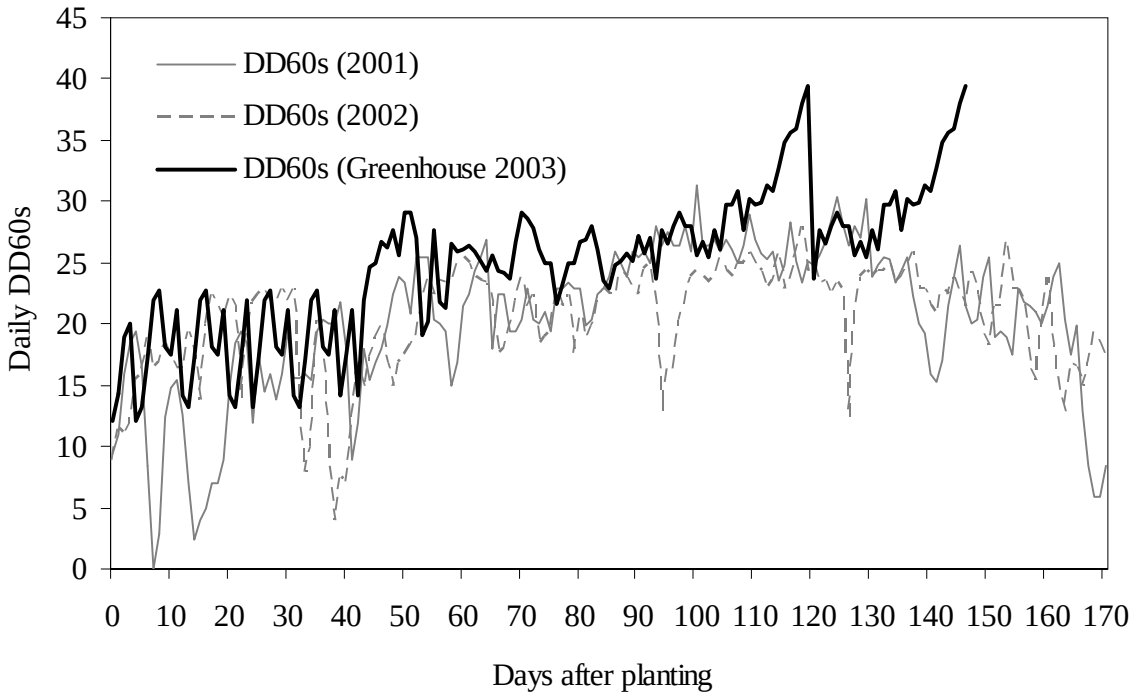

Fig. 82. Comparison of daily growing degree days (DD60s) for the 2001 and 2002 field and the 2003 greenhouse studies from planting to harvest.

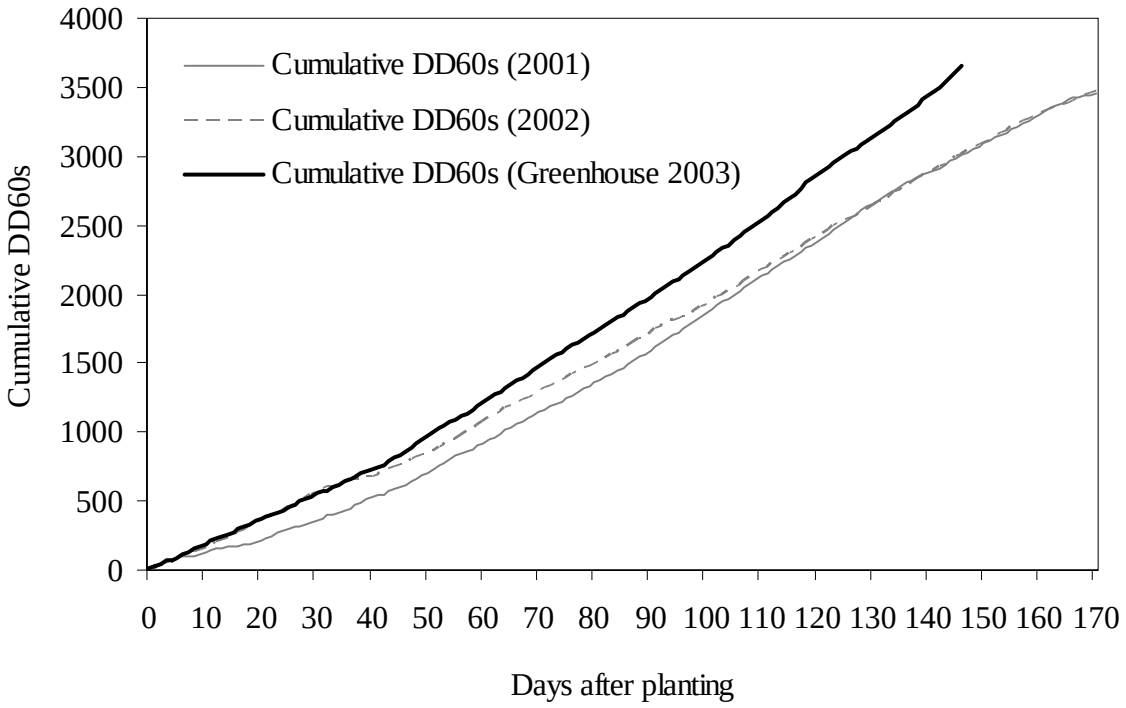

Fig. 83. Comparison of cumulative growing degree days (DD60s) for the 2001 and 2002 field and the 2003 greenhouse studies from planting to harvest.

Plant Biomass Partitioning and Plant Mapping – Cutout

Biomass partitioning for the greenhouse study was evaluated two days after cotton cutout, which occurred 76 DAP. The cultivar differences observed in plant height at cutout are confirmed by examining stem dry weights. ST4892BR had greater stem weight than ST474 (Fig. 84). ST4793R had numerically greater stem weight than ST474 but was not different from either ST4892BR or ST474. Leaf biomass was also different among cultivars. Both transgenic cultivars had greater leaf dry weight per plant (Fig. 85). The leaf area follows this same trend, although the differences were not significant (Fig. 86). The partitioning of fruit as a percentage of total plant dry weight was not different between cultivars with all cultivars allocating approximately 19 to 21 percent of biomass into fruiting structures (Fig. 87).

Cultivar had an effect on total boll production with ST4892BR and ST4793R producing approximately 3.8 and 3.0 more bolls plant^{-1}, respectively than ST474 (Fig. 88). The mean boll dry weight was approximately 1.2 g boll^{-1} for all cultivars (Fig. 89). Furthermore, boll numbers at fruiting positions 1, 2, and 3 did not differ significantly between cultivars (Fig. 90). The increase in total boll numbers (Fig. 88) for ST4892BR and ST4793R reflects the numerical increases apparent at each of these fruiting sites (Fig. 90). A significant contribution to ST4892BR yield originated from vegetative bolls (Fig. 91). The percentage of total fruit retained for fruiting positions 1 through 4 throughout all sympodia averaged approximately 93 % for transgenic and conventional cultivars (Data not shown).

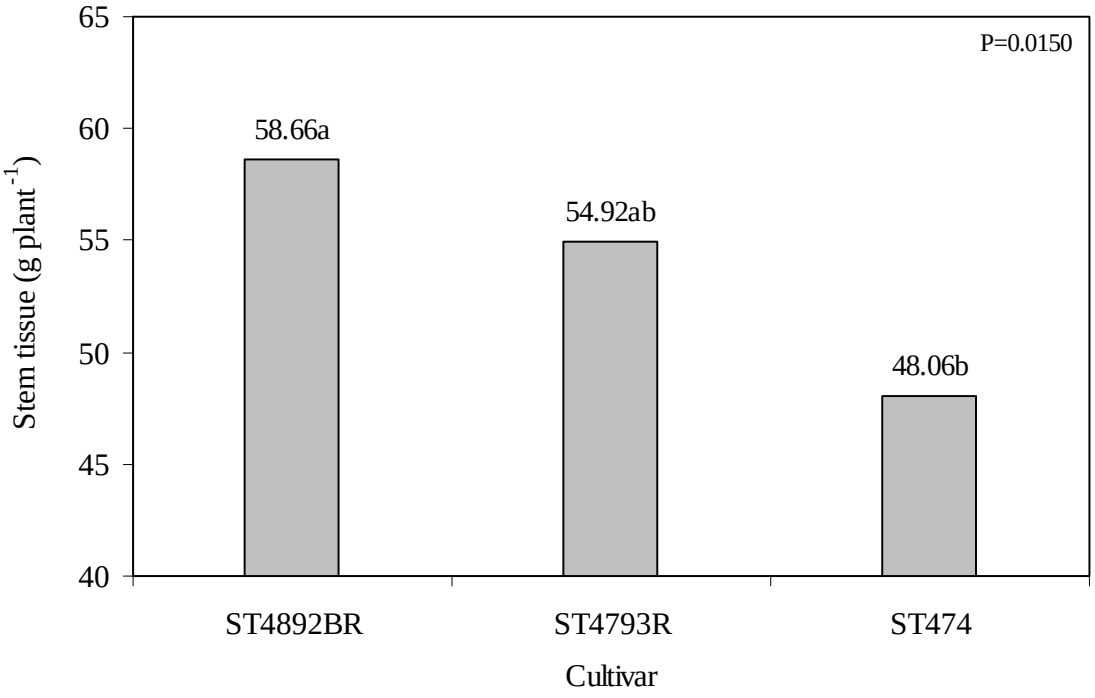

Fig. 84. Dry weight of stem tissue per plant at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

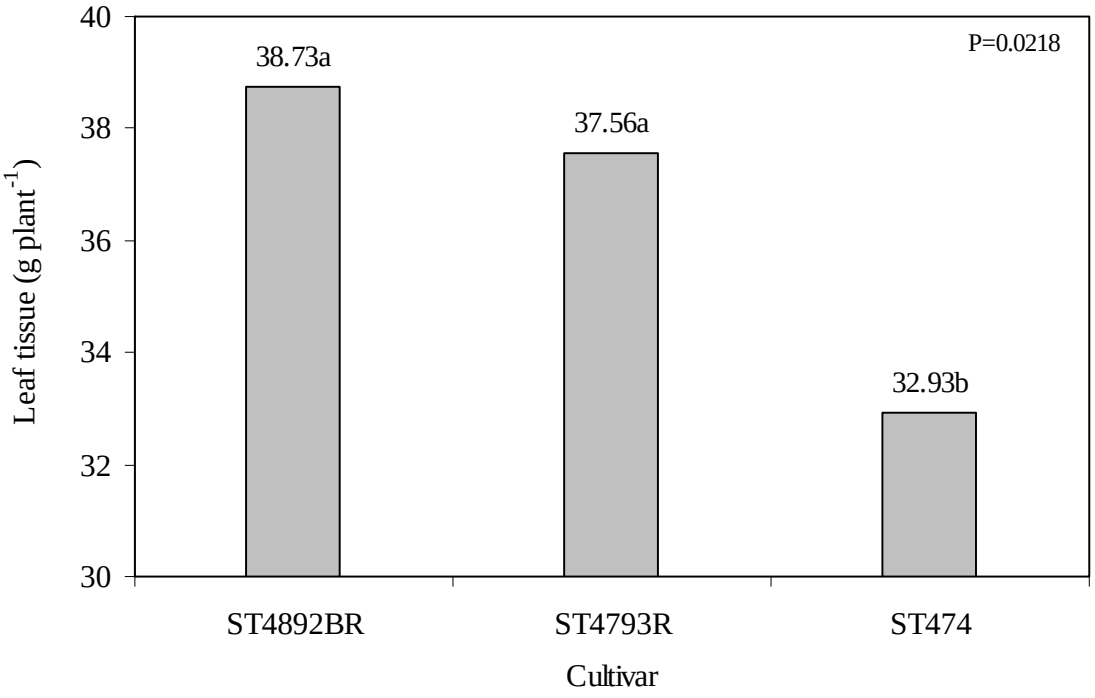

Fig. 85. Dry weight of leaf tissue per plant at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure.

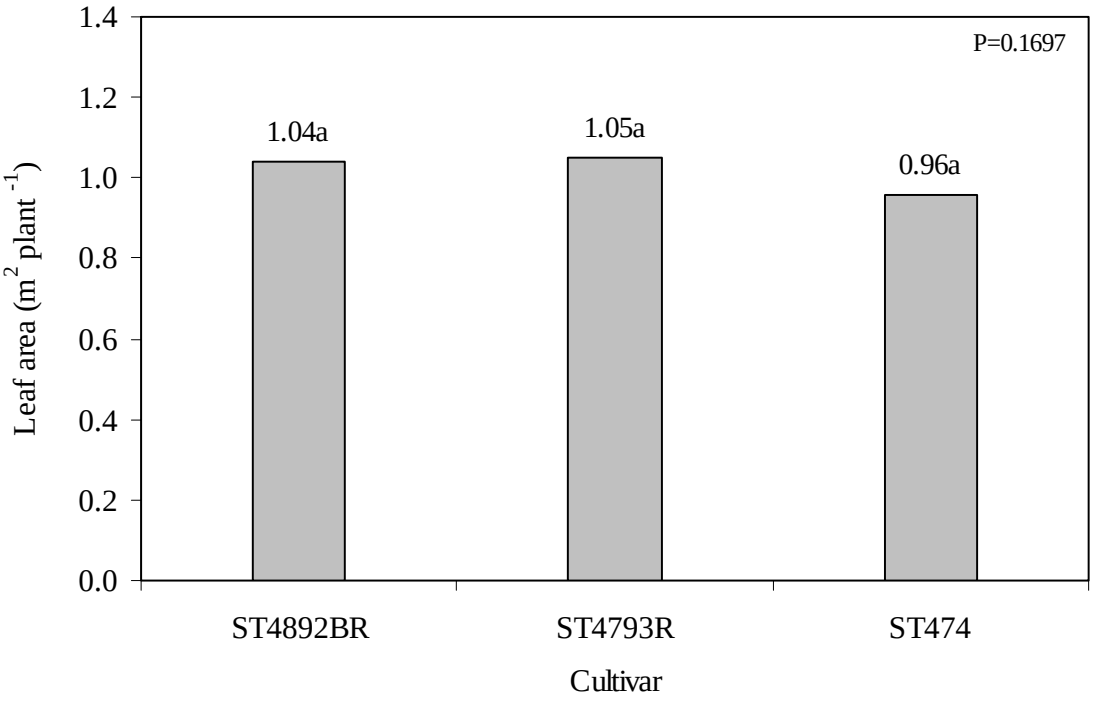

Fig. 86. Leaf area per plant at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

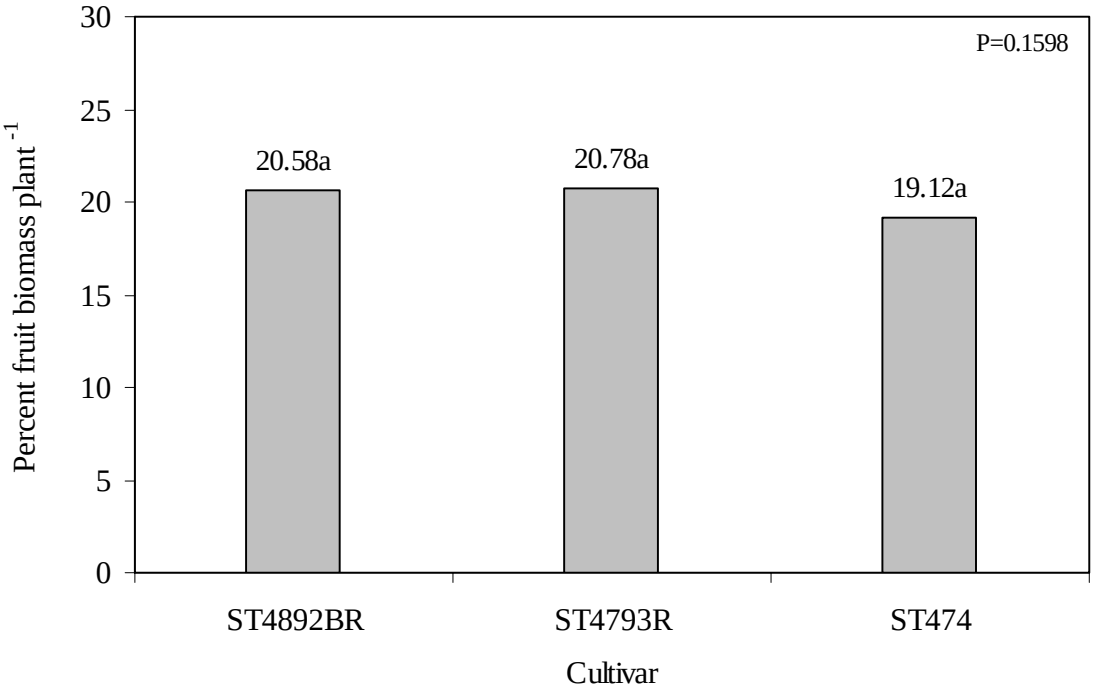

Fig. 87. Percent of total plant biomass partitioned as fruit at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

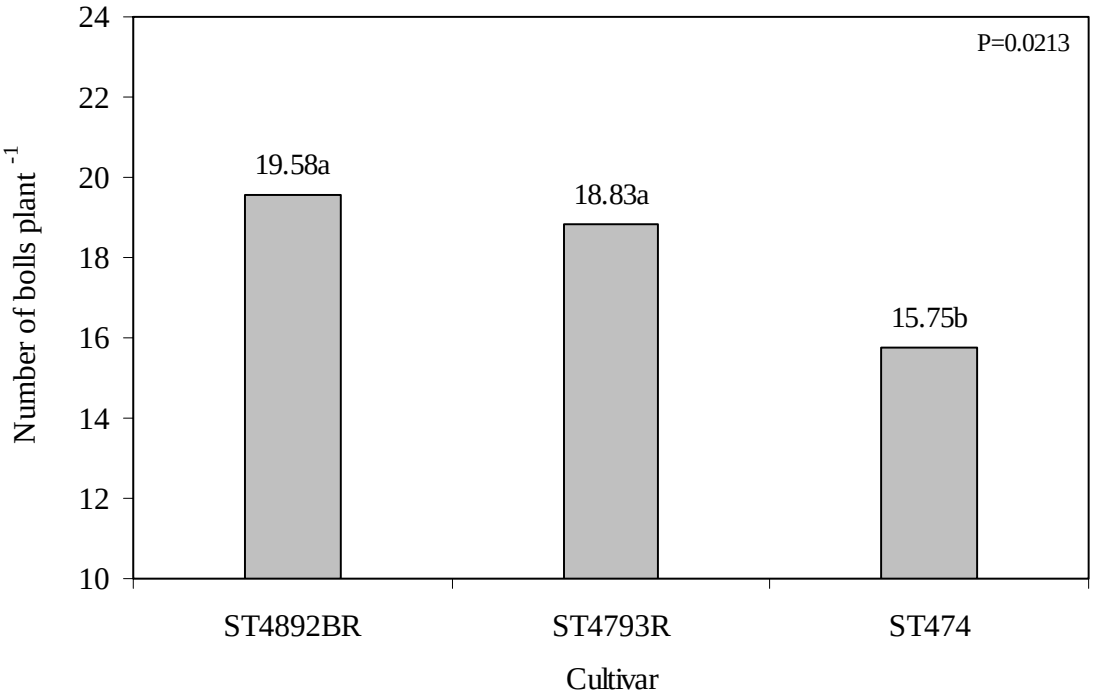

Fig. 88. Total number of bolls per plant at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

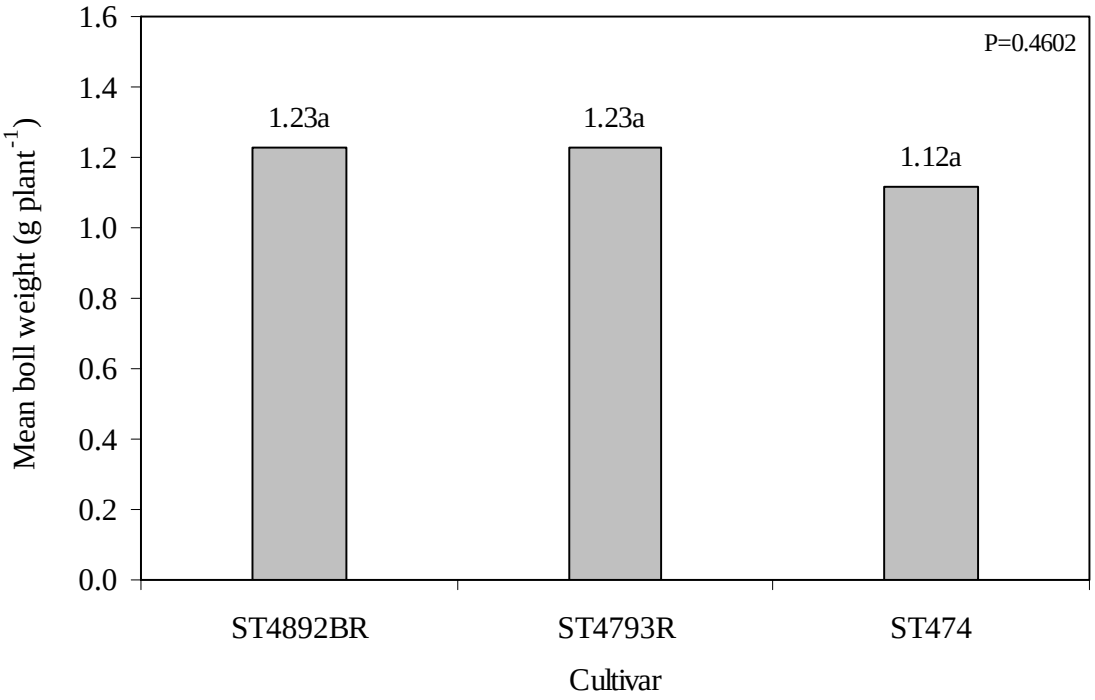

Fig. 89. Mean boll dry weight per plant at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

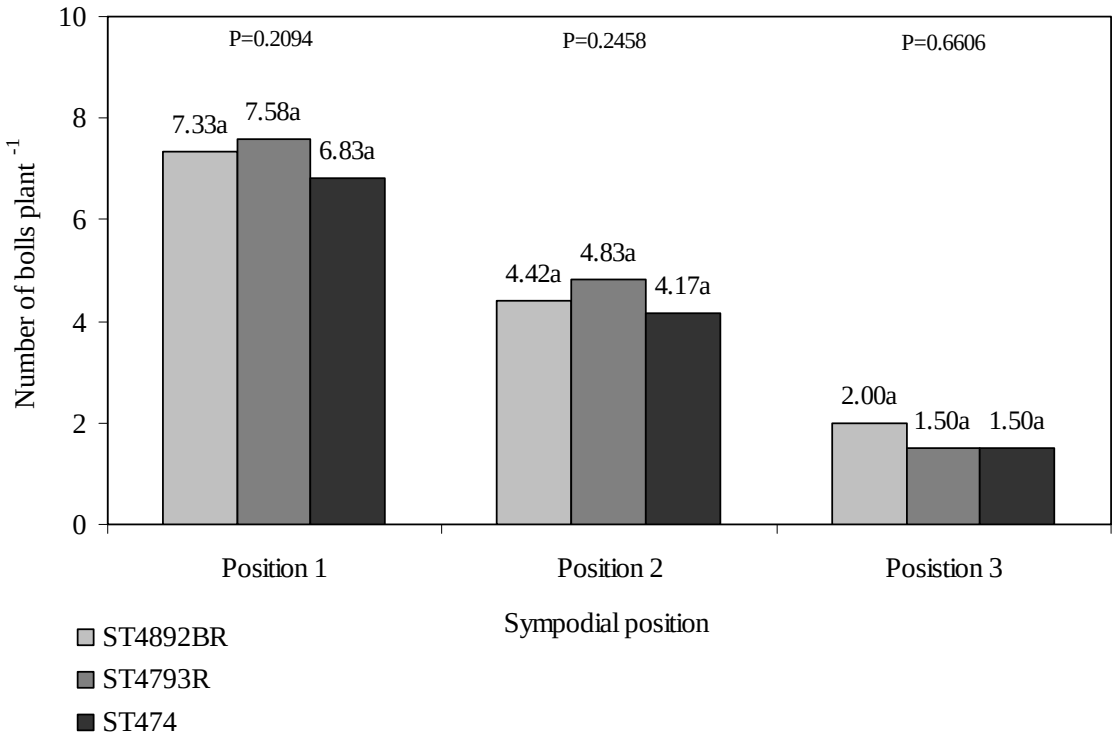

Fig. 90. Number of bolls located at fruiting positions 1 through 3 per plant at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

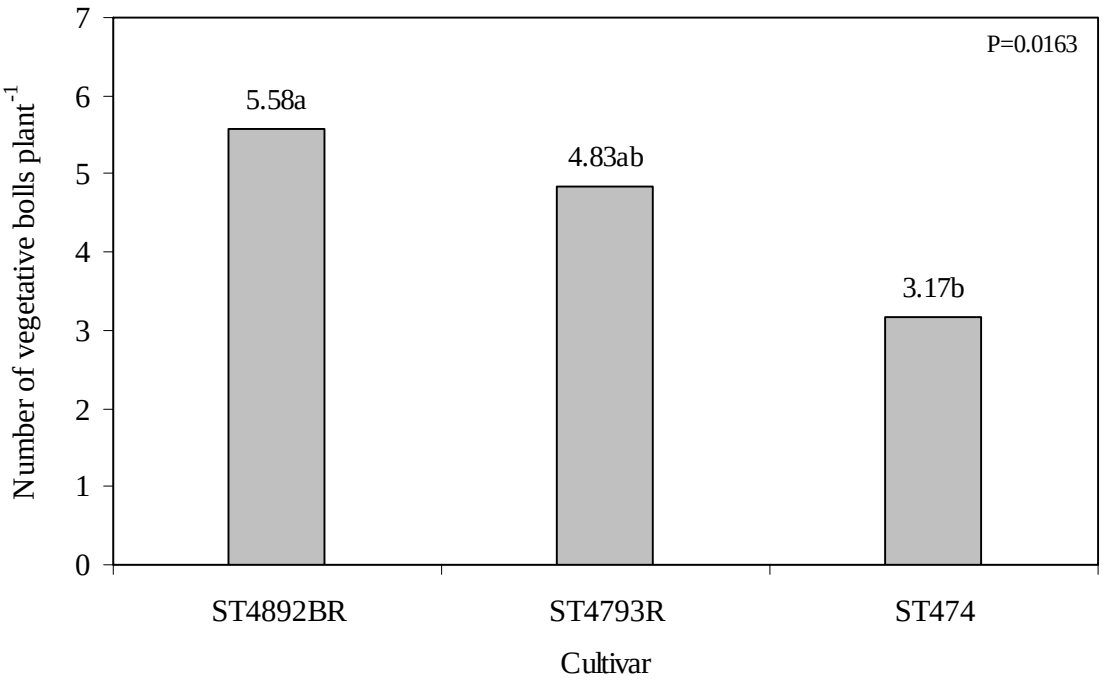

Fig. 91. Number of vegetative bolls per plant at cutout for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

The results for biomass partitioning of IR treatments generally reflected those observed in the field study. Application of IR treatments had little effect on stem dry weight (Fig. 92) and total amount of biomass partitioned as leaf tissue (Fig. 93). Both parameters showed slight numerical reductions in biomass for the NP+FP treatment. This trend contradicts the pattern for stem and leaf dry weights observed in the field study. Based on the numerical reduction in biomass (Fig. 92), the trend for shorter average internode length of the NP+FP treatment from 38 to 90 DAP (Fig. 81) may have been attributed to plant stress from NP+FP applications in the greenhouse. If addition of FP resulted in plant stress, the consequence could be reduction in dry matter production. Neither the internode length nor stem and leaf biomass was significantly reduced as a result of NP+FP treatments. The trends for leaf area reflected those for leaf dry weights indicating that IR applications did not affect leaf size or thickness (Fig. 94). The partitioning of fruit as a percentage of total plant dry weight was not different between IR treatments with all treatments allocating approximately 20 percent of total plant biomass into fruiting structures (Data not shown). Generally, these data show that IR applications did not affect the partitioning of biomass within the plant at cutout.

Plant Mapping – Harvest

Plant mapping at harvest did not reveal any substantial differences for cultivar and IR main effects. Total boll numbers plant^{-1} and mean boll weight were not different among cultivar and IR treatments. There were differences in boll distribution among sympodial positions for cultivars. ST474 and ST4793R had significantly more first position bolls than ST4892BR (Fig. 95). These data contradict that from the field study

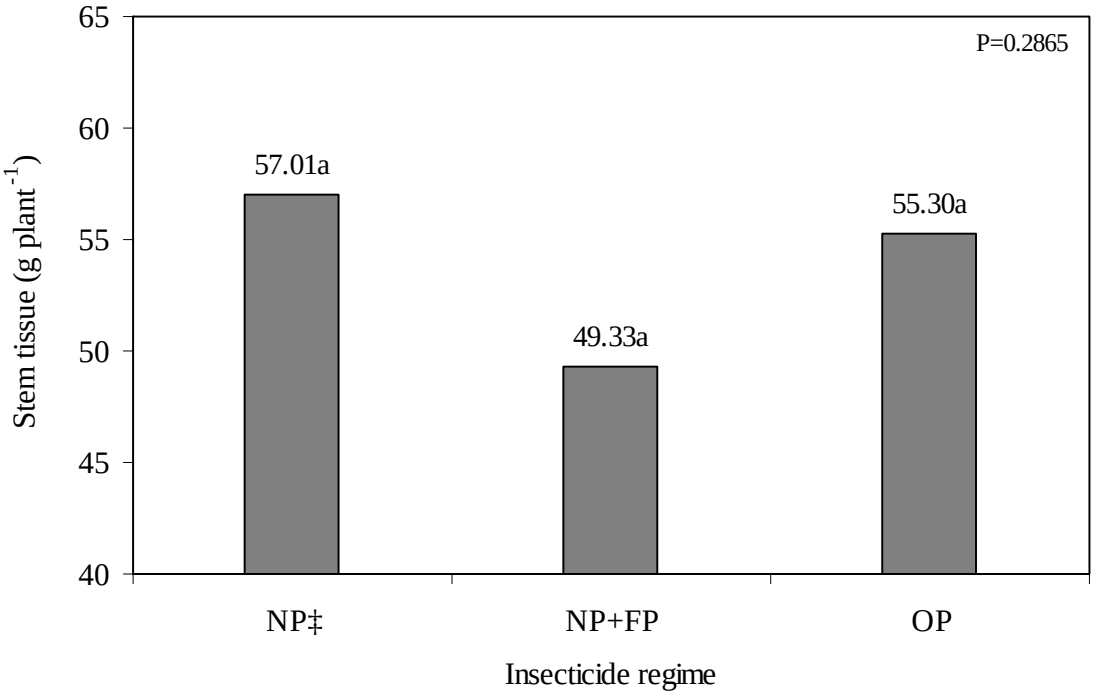

Fig. 92. Dry weight of stem tissue per plant at cutout for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

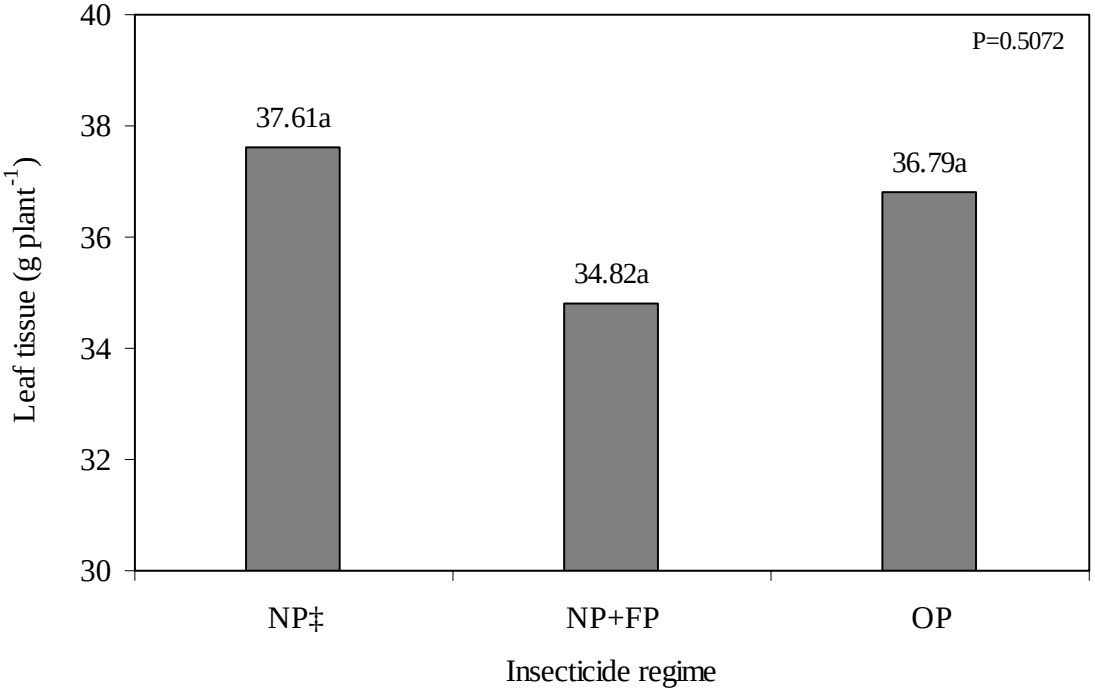

Fig. 93. Dry weight of leaf tissue per plant at cutout for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

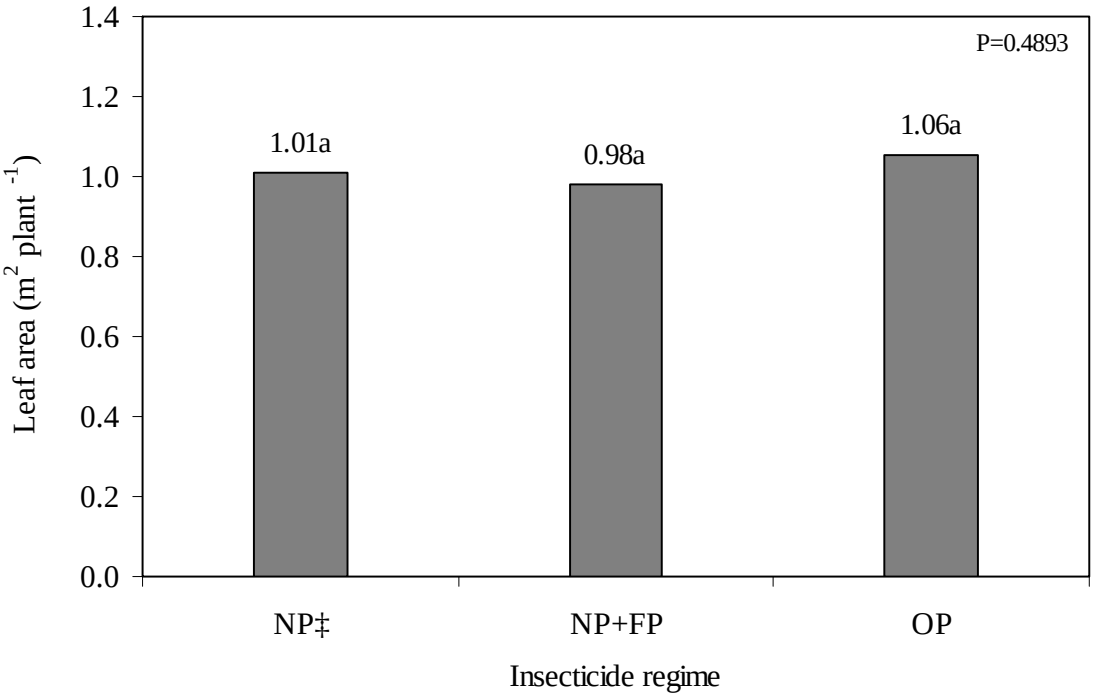

Fig. 94. Leaf area per plant at cutout for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

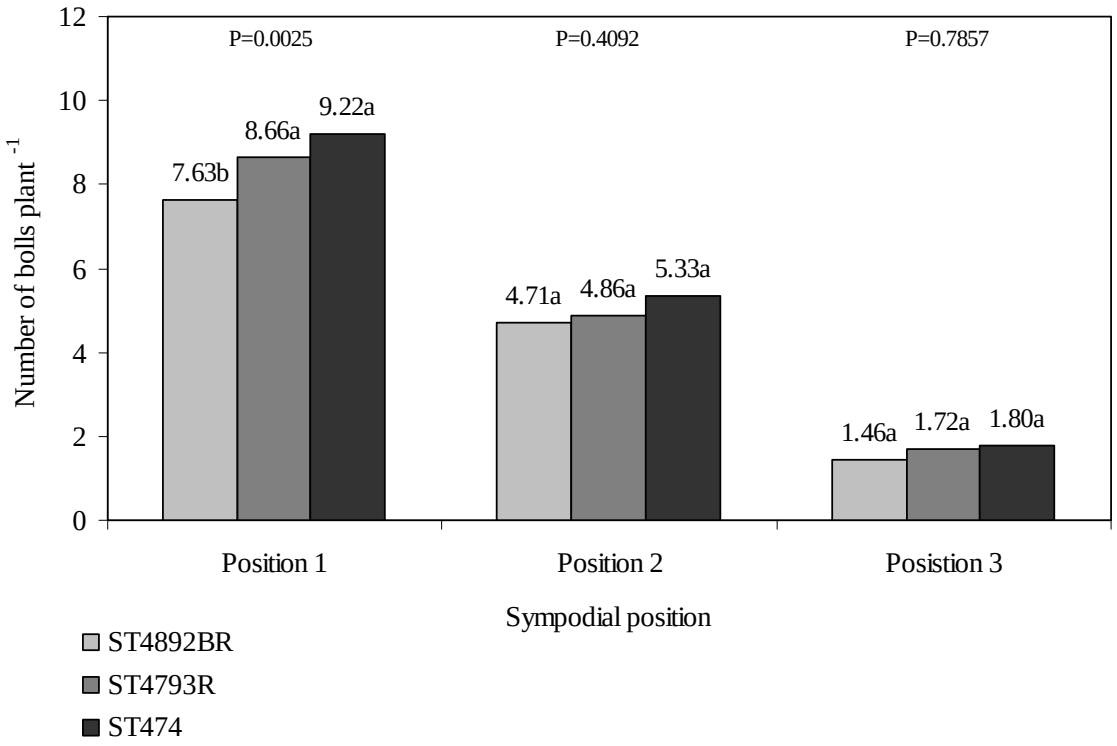

Fig. 95. Number of harvestable bolls located at fruiting positions 1 through 3 per plant for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure.

which showed ST4892BR having significantly more first position bolls than ST4793R and ST474. Furthermore, under field conditions, ST4892BR produced more total bolls than the other two cultivars. Mean boll weights at fruiting positions 1, 2, and 3 were not different among the cultivars in the greenhouse study (Fig. 96).

Examination of boll numbers in sympodial ranges 6 through 10 failed to show any differences (Fig. 97). However, ST474 contained approximately one more boll within sympodial range 11 through 15. This is further reflected in assessing the seedcotton contribution of sympodial ranges as a percentage of final yield. ST474 had a larger (P=0.0580) percentage of seedcotton contribution from sympodia 11 through 15 than ST4892BR (Fig. 98). ST4793R was not different from the other cultivars in this sympodial range. There were no significant cultivar differences in seedcotton contribution for sympodia 6 through 10 or 16 through 20. However, the numerical trends for sympodia 6 through 10 reflect those increases observed in the yield for ST4892BR.

This evaluation revealed the difference in fruit distribution for greenhouse compared to field conditions. In the greenhouse, approximately 60 and 40 percent of seedcotton was distributed in sympodial ranges 6 through 10 and 11 through 15, respectively. In the field study, the largest percentage of yield contribution came from sympodial range 11 through 15. The shift in yield distribution from lower sympodia to mid-plant sympodial branches, in the field, may be a response to leaf shading of lower sympodia (Kerby and Hake, 1996) as well as indications of early season fruit loss to insects.

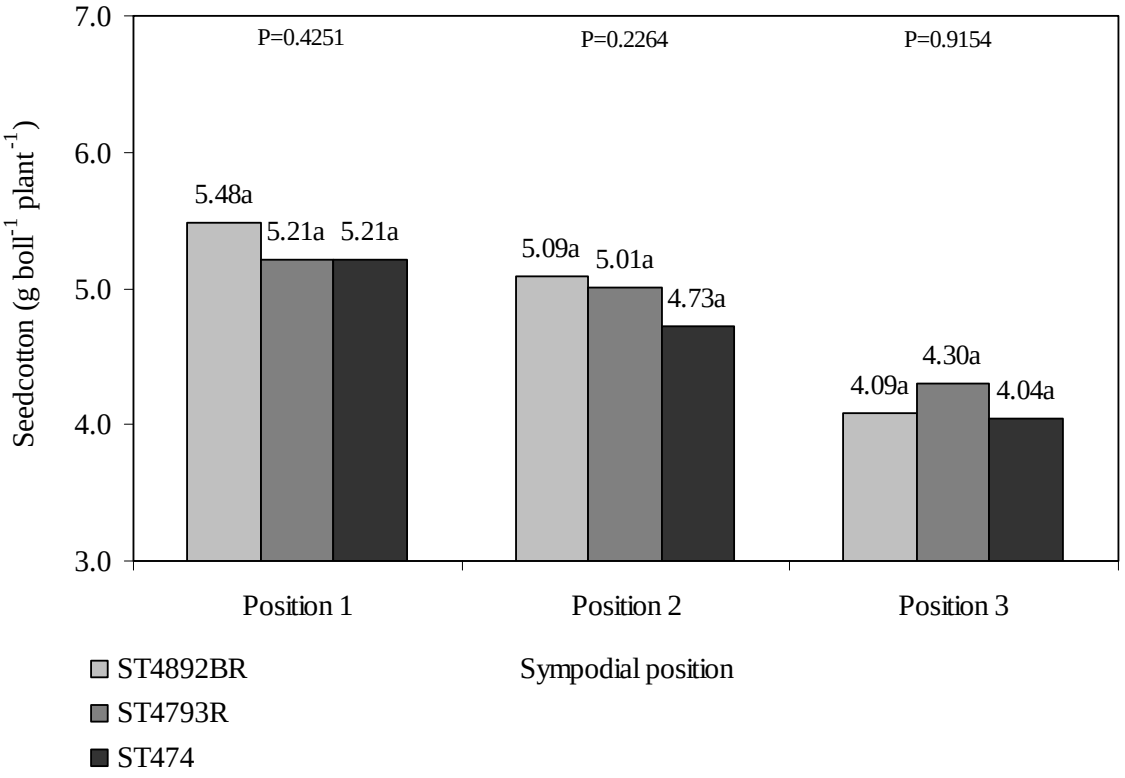

Fig. 96. Mean seedcotton weight for bolls located at fruiting positions 1 through 3 for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure.

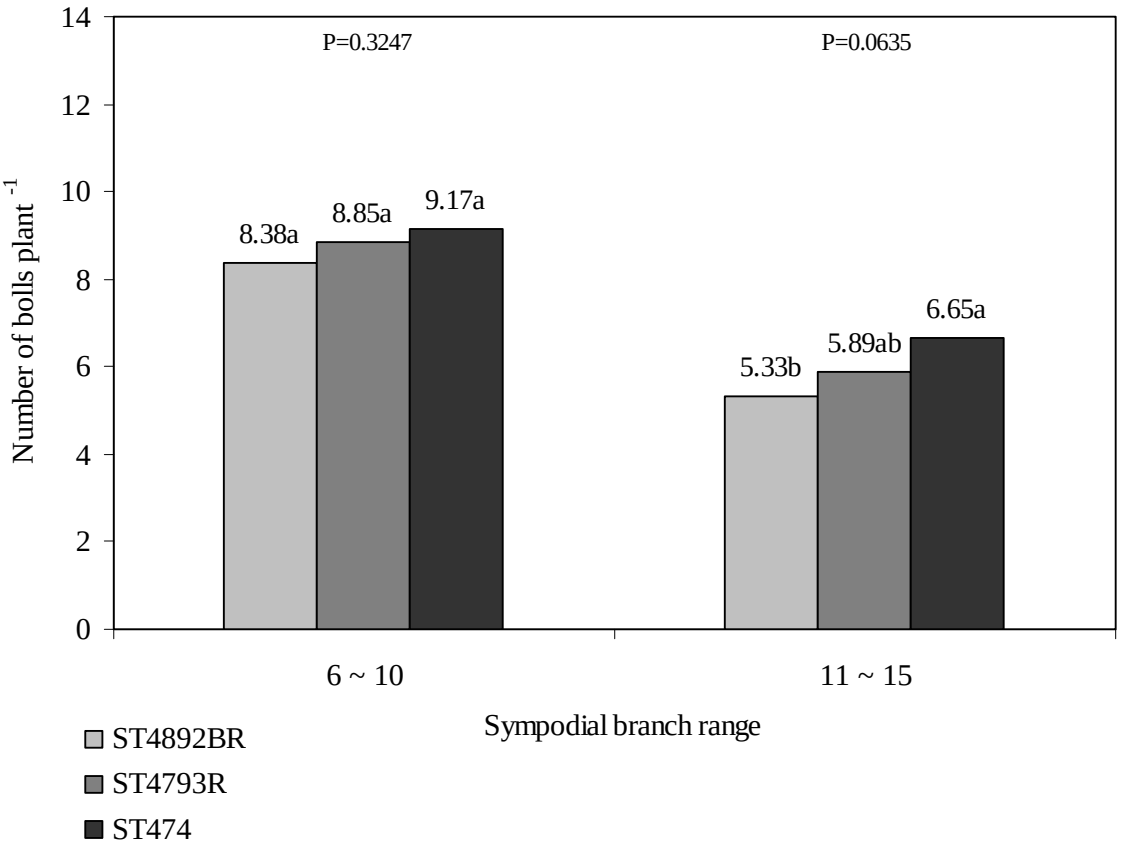

Fig. 97. Number of harvestable bolls located on sympodia 6 through 15 per plant for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

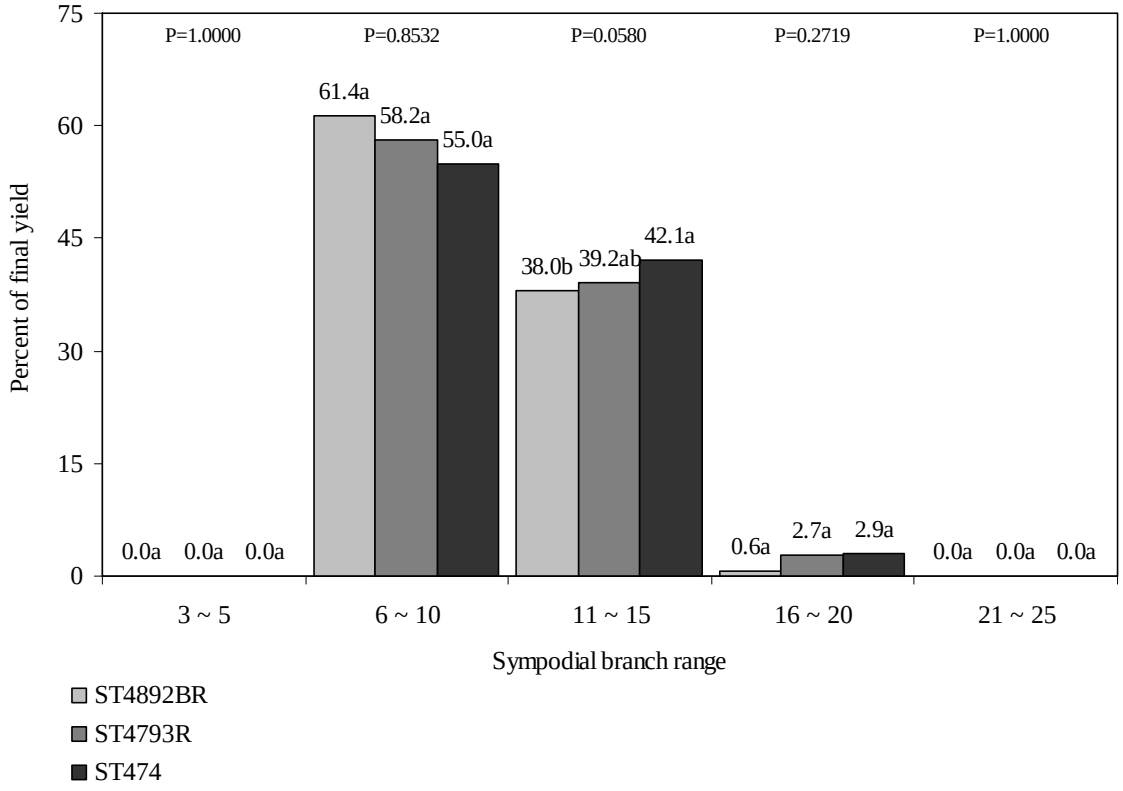

Fig. 98. Seedcotton contribution of sympodial ranges as a percentage of final yield for three cotton cultivars in the greenhouse study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure.

IR treatments had a significant impact on the number of bolls at fruiting positions 1 and 2 (Fig. 99). Addition of FP added approximately one more (P=0.1050) first position boll compared to NP alone. Conversely, use of FP reduced (P=0.0796) second position bolls by approximately one boll compared to NP. This may be the primary reason for yield similarities between NP and NP+FP. Cotton response to OP was not different from NP or NP+FP relative to boll numbers at fruiting positions one through three. Mean boll weights at fruiting positions 1 through 3 did not respond significantly to any IR treatment, although numerical trends reflecting those observed in yield were evident (Fig. 100). Furthermore, the seedcotton distribution among sympodia was not affected by IR treatments (Data not shown). Some differences were found in boll distribution among fruiting positions for NP and NP+OP. Therefore, seedcotton contribution of sympodial ranges as a percentage of final yield was examined to investigate the magnitude of this effect across plant architecture (Fig. 101). This assessment confirmed that the differences in fruiting position characteristics were not localized to a specific sympodial range. Generally, the NP+FP treatment only appeared to increase the number of first position bolls; however, the reduction in second position bolls negated any yield increase over NP. No significant cultivar by IR treatment interactions were detected for the data presented in the greenhouse study section of this document, which suggests that the three cultivars responded similarly to all levels of IR treatment applications.

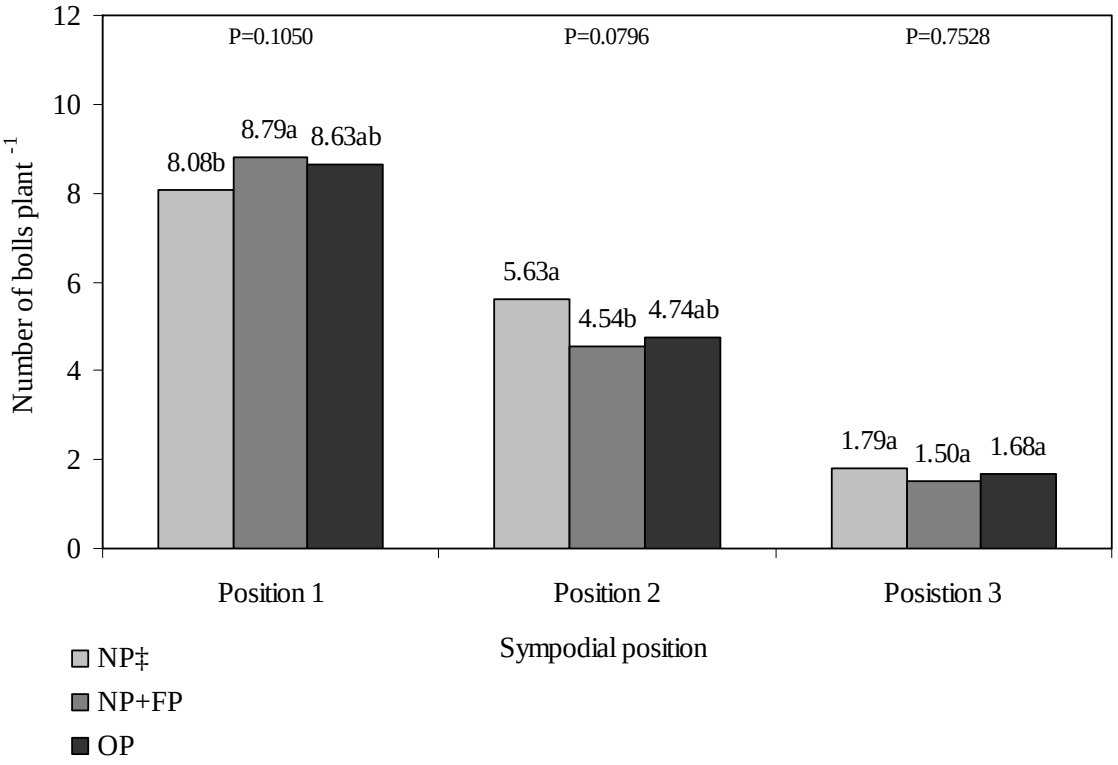

Fig. 99. Number of harvestable bolls located at fruiting positions 1 through 3 per plant for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at P<0.10 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

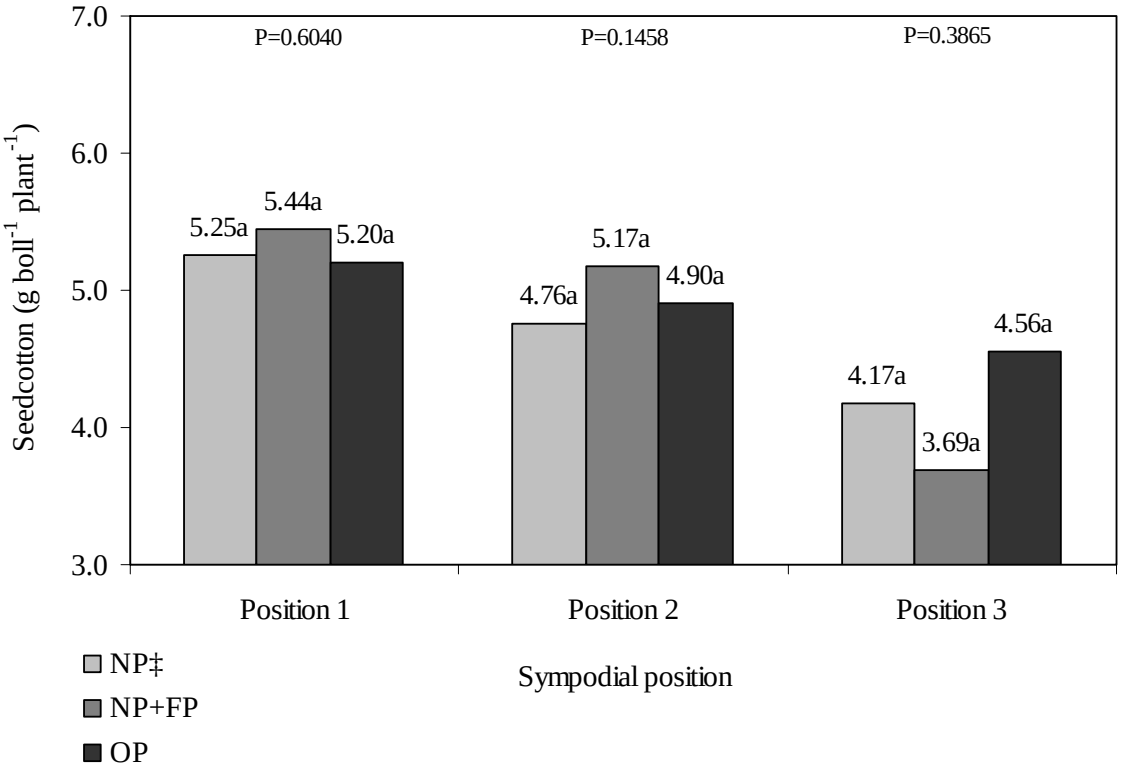

Fig. 100. Mean seedcotton weight for bolls located at fruiting positions 1 through 3 for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at $P<0.05$ according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

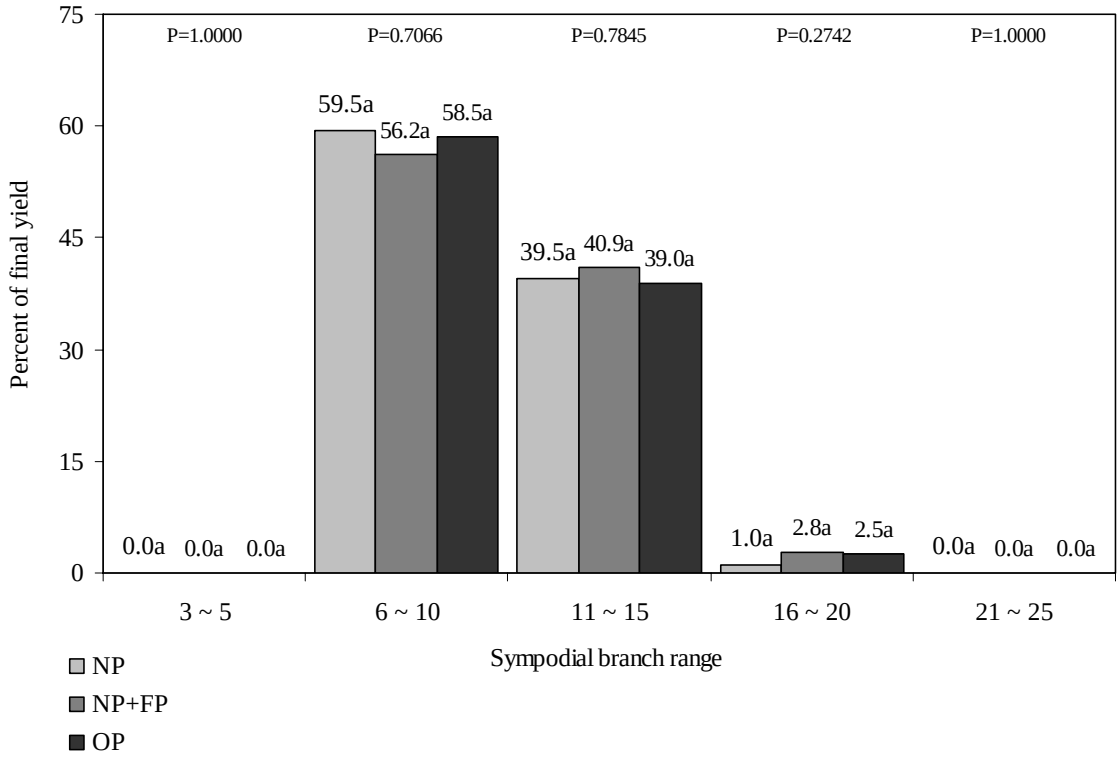

Fig. 101. Seedcotton contribution of sympodial ranges as a percentage of final yield for insecticide regime (IR) treatments in the greenhouse study. Means followed by the same letter are not statistically different at P<0.05 according to the Tukey-Kramer procedure. ‡The following designations were used to denote IR treatments: NP, non-phosphate insecticide treatment (control); NP+FP, non-phosphate + foliar phosphorus treatment; and OP, organophosphate insecticide treatment.

CONCLUSIONS

Genetically modified cotton acreage has increased dramatically over the last six years. Reports of variable results in fiber quality and yield have arisen regarding transgenic cultivars. Previous research exhibits inconsistencies in performance of stacked-gene and Roundup Ready® cultivars compared to the respective recurrent parent cultivar. Some changes in production practices have occurred coincident with the introduction of transgenic technology, such as reduced use of broad-spectrum insecticides including organophosphates and less cultivation that could potentially influence the growth and yield of cotton. One factor that might affect these parameters is the difference in the amount of foliar-applied P between an OP and NP insecticide regime. Therefore, a study was conducted under field and greenhouse conditions to investigate performance of transgenic and conventional cotton and determine the efficacy of OP and NP treatments on growth characteristics, yield, and fiber quality of cotton.

Cotton lint yield in the field study was substantially affected by cultivar. ST4892BR produced greater lint yields than ST4793R and ST474. These results are consistent with Bosch et al. (2002) who reported cultivars containing the Bollgard® transgene had consistent yield advantages compared to non-Bollgard® cultivars. Furthermore, Moser et al. (2001) found that stacked-gene cultivars produced lint yields that were equivalent to or significantly greater than lint yields of their respective conventional counterparts. In the field study, the lint yields for ST4793R were significantly less than ST4892BR but not different from ST474. This finding supports

the work of Moser et al. (2001) who reported Roundup Ready® cultivars produced lint yields that were similar to their conventional parent. Analysis of yield components revealed the stacked-gene cultivar had significantly larger bolls and contained considerably more bolls per plant than the other two cultivars. The increase in total bolls for ST4892BR was predominantly isolated to sympodia 6 through 10. Furthermore, a significant increase in the number of first position bolls was observed for ST4892BR. As a result, this may have substantially influenced mean boll weight since bolls on lower sympodia and those closer to the main stem, compared to distal positions, are larger and therefore contribute more towards yield (Ashley, 1972; Wullschleger and Oosterhuis, 1990; Kerby and Ruppenicker, 1992; Parvin and Atkins, 1997).

Application of IR treatments exerted some influence on lint yields in the field study. Although the differences were not significant at the 5% level, there was evidence that cotton treated with FP responded with a yield increase compared to NP and OP treatments. OP had no effect on lint yields or yield components. Examination of yield components revealed the yield increase for NP+FP was primarily due to an increase in the number of second position bolls. Furthermore, the increase in second position boll numbers was predominantly isolated to sympodial branches 6 through 10. Cotton also responded to NP+FP by significantly increasing the number of bolls located on sympodia 21 through 25. While yield from this sympodial range does not contribute significantly to final yield (approximately 1.6% of yield), this increase suggests that the additional P may have affected boll set. Coincidentally, the NP+FP treatments containing the greatest amount of P per treatment were applied during fruit set in this

nodal range. Furthermore, it suggests that plants receiving NP+FP may have been able to maintain the boll load without shedding fruit. In this trial, fruit set in this range coincided with cotton cutout, a period when all available photosynthate is consumed by developing fruit resulting in cessation of vegetative growth.

Cultivar had little effect on lint quality in this study. The conventional cultivar produced longer fibers than the Roundup Ready® line, and because the values were in the discounted range, the conventional cultivar could have resulted in a smaller discount. Fiber length of ST4892BR was not different from its counterparts, although its mean length was slightly greater than ST4793R. The fiber results for the cultivars studied support the conclusions of Moser et al. (2001) who reported that fiber length of some transgenic cultivars was shorter than that of their conventional parents. IR treatments did not significantly affect any of the fiber quality characteristics examined.

Plant height at peak bloom and cutout was greater for ST4892BR compared to ST474, while each cultivar maintained the same number of main-stem nodes. In turn, ST474 had a shorter average internode length than ST4892BR. Although this change in internode length could suggest a possible shift in allocation of carbohydrates from vegetative to reproductive growth, this response did not result in a yield advantage for ST474. ST4793R was similar in height and number of nodes to both counterparts. End-of-season plant height and nodes were equivalent for all cultivars. ST4793R partitioned more plant biomass into leaf and stem tissue than ST474 by peak bloom, which coincides with the visual observation that ST4793R had a more rank appearance compared to ST474 during the season.

Leaf tissue analysis revealed similar leaf P concentrations for NP+FP and OP treatments, suggesting that plants acquire P from OP insecticides. Based on the yield response to NP+FP, yields from OP treatment should have been similar to that of NP+FP if plants were utilizing the P intrinsic to OP compounds as efficiently as may have been the case with the NP+FP treatment. However, lint yield was not influenced by OP applications. The lack of response may be evidence that the P component of OP is not utilized as effectively as that contained in foliar fertilizers. No differences were observed regarding leaf tissue P concentrations for ST4892BR and ST474.

Results from the greenhouse study did not provide conclusive support of the field observations for either cultivar or IR main effects. Although slight variations in yield component and distribution characteristics were observed, a yield advantage did not result from cultivar or IR main effects. Both transgenic versions accumulated more leaf and stem biomass than the conventional cultivar by cotton cutout, although the ST4793R stem biomass increase was not significant. The stem weight contrast was primarily a function of increased height over the conventional parent. None of the early-season plant growth characteristics associated with a particular technology type contributed to a yield advantage. IR applications did not exert any influence on growth parameters or biomass partitioning elements during the growing season.

This research study showed definitive benefits of stacked-gene transgenic cotton over its Roundup Ready® and conventional parent for this Stoneville seed line, especially in terms of lint yield. Cultivar response to foliar IR treatments was similar for all growth, yield, and fiber quality parameters presented in this document. OP

insecticides did not influence the growth, yield, or fiber quality characteristics of cotton. Results from this study indicate a potential benefit from FP use in cotton, even when adequate soil-test P levels are present. While conclusive evidence exists regarding cultivar yield differences, this study does not provide sufficient evidence to conclude that OP insecticides influence growth, yield, or fiber quality characteristics of these cotton cultivars.

REFERENCES

Adkisson, P., T. Archer, J. Benedict, R. Frisbie, P. Morrison, P. Pietrantonio, and G. Teetes. 1999. Position statement on insect-resistant transgenic crops: Potential benefits and risks. Available at: http://agfacts.tamu.edu/~jbenedic/TRANS.htm

Andrews, G., B. Atkins, C. Collison, D. Boykin, D. Hardee, A. Harris, B. Layton, W. McCarty, P. McKibben, J. Phelps, J. Reed, J. Robbins, G. Snodgrass, S. Stewart, and M. Williams. 2001. Cotton insect control guide 2001. Mississippi State Univ. Ext. Service, Mississippi State, MS. pub. 343.

Ashley, D.A. 1972. ^{14}C-labeled photosynthate translocation and utilization in cotton plants. Crop Sci. 12:69-74.

Barber, S.A., J.M. Walker, and E.H. Vasey. 1963. Mechanisms for the movement of plant nutrients from the soil and fertilizer to the plant root. J. Agric. Food Chem. 11:204-207.

Barrow, N.J. 1980. Evaluation and utilization of residual phosphorus in soils. p. 335-355. *In* The role of phosphorus in soils. F.E. Khasawneh, E.C. Sample, and E.J. Kamprath, eds. Madison, WI. Am. Soc. Agron.

Bassett, D.M., W.D. Anderson, and C.H.E. Werkhoven. 1970. Dry matter production and nutrient uptake in irrigated cotton (*Gossypium hirsutum*). Agron. J. 62:299-303.

Bauer, P.J. and Cothren, J.T. 1990. Growth-promoting activity of chlordimeform. Agron. J. 82:73-75.

Bednarz, C.W., N.W. Hopper, and M.G. Hickey. 1998. Effects of foliar fertilization of Texas Southern High Plains cotton: Leaf nitrogen and growth parameters. J. Prod. Agric. 11:80-84.

Bednarz, C.W., N.W. Hopper, and M.G. Hickey. 1999. Effects of foliar fertilization of Texas Southern High Plains cotton: Leaf phosphorus, potassium, zinc, iron, manganese, boron, calcium, and yield distribution. J. Plant Nutr. 22(6):863-875.

Bednarz, C.W., D.C. Bridges, and S.M. Brown. 2000. Analysis of cotton yield stability across population densities. Agron. J. 92:128-135.

Benedict, C.R., and R.J. Kohel. 1975. Export of ^{14}C-assimilates in cotton leaves. Crop Sci. 15:367-372.

Bosch, J., S. Fuchs, D. Pustejovsky, and D. Albers. 2002. Yield and economic comparison of Bollgard varieties in the Texas gulf coast region. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. Available on: cdrom.

Boquet, D.J., E.B. Moser, and G.A. Breitenbeck. 1993. Nitrogen effects on boll retention of field-grown cotton. Agron. J. 85:34-39.

Boquet, D.J., E.B. Moser, and G.A. Breitenbeck. 1994. Boll weight and within-plant yield distribution in field-grown cotton given different levels of nitrogen. Agron. J. 86:20-26.

Boquet, D.J., and A.B. Coco. 1996. Yield response of irrigated and rainfed cotton to row spacing, N rate and plant population density. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 2:1384-1386.

Boquet, D.J. and E.B. Moser. 2003. Boll retention and boll size among intrasympodial fruiting sites in cotton. Crop Sci. 43:195-201.

Bourland, F.M., D.M. Oosterhuis, and N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main-stem node counts. J. Prod. Agric. 5:532-538.

Bryant, K.J., W.C. Robertson, G. Lorenz, C.T. Allen, F.M. Bourland, and L. Earnest. 2000. Economic evaluation of transgenic cotton systems in Arkansas. p. 38-43. Proc. Cotton Research Meeting. AAES Special Report 198.

Burris, E., G.B. Padgett, J. Price, and K. Sanders. 2001. Assessing the effects of planting date, seeding rate and fungicide on cotton stand and yield. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:150-151.

Crozier, C.R. 2004. 2004 North Carolina cotton production guide. p. 52. North Carolina Cooperative Extension Service, North Carolina State Univ., Raleigh, NC. Available at: http://ipm.ncsu.edu/Production_Guides/cotton/chptr7.pdf.

Edge, J.M., J.H. Benedict, J.P. Carroll, and K.H. Reding. 2001. Contemporary Issues: Bollgard cotton: An assessment of global economic, environmental, and social benefits. J. Cotton Sci. 5:121-136.

Ethridge, M.D., and E.F. Hequet. 2000. Fiber properties and textile performance of transgenic cotton versus parent varieties. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:731-737.

Feagley, S.E., M.S. Valdez, and W.H. Hudnall. 1994. Papermill sludge, phosphorus, potassium, and lime effect on clover grown on a mine soil. J. Environmental Quality. 23(4):759-765.

Galadima, A., S.H. Husman, and J.C. Silvertooth. 2003. Plant population effect on yield and fiber quality of three upland cotton varieties at Maricopa Agricultural Center, 2002. Arizona Cotton Report, Univ. of Arizona College of Agric. and Life Sci., Tucson, AZ. Available at: http://cals.arizona.edu/pubs/crops/az1312.

Gerik, T.J., W.D. Rosenthal, C.O. Stockle, and B.S. Jackson. 1989. Analysis of cotton fruiting, boll development, and fiber properties under nitrogen stress. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:64-67.

Gipson, J.R. 1986. Temperature effects on growth, development, and fiber properties. p. 48-49. *In* Cotton physiology. J.R. Mauney and J.McD. Stewart, eds. The Cotton Foundation. Memphis, TN.

Hake, K.D., D.M. Bassett, T.A. Kerby, and W.D. Mayfield. 1996a. Producing quality cotton. p. 134-149. *In* Cotton production manual. S.J. Hake, T.A. Kerby, and K.D. Hake, eds. Univ. of California Division of Agriculture and Natural Resources, Oakland, CA. pub. 3352.

Hake, S.J., K.D. Hake, and T.A. Kerby. 1996b. Early- to mid-bloom decisions. p. 51-63. *In* Cotton production manual. S.J. Hake, T.A. Kerby, and K.D. Hake, eds. Univ. of California Division of Agriculture and Natural Resources, Oakland, CA. pub. 3352.

Halevy, J. 1976. Growth rate and nutrient uptake of two cotton cultivars grown under irrigation. Agron. J. 68:701-705.

Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. Soil fertility and fertilizers, 6th ed. p. 155-156. Prentice Hall, Upper Saddle River, NJ.

Hernandez-Jasso, A., and J. Gutierrez-Zamoran. 2000. Response to plant density in cotton cultivars, yield and yield components. Yaqui Valley, Sonora Mexico. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:568-570.

Holford, I.R.C. 1997. Soil phosphorus: Its measurement, and its uptake by plants. Aust. J. Soil Res. 35:227-239.

Hons, F.M., N.W. Hopper, and T.V. Hicks. 1990a. Applied phosphorus and potassium effects on the emergence, yield, and planting seed quality of cotton. J. Prod. Agric. 3:337-340.

Hons, F.M., L.A. Larson-Vollmer, and M.A. Locke. 1990b. NH_4Oac-EDTA extractable phosphorus as a soil test procedure. Soil Sci. 149:249-256.

Jenkins, J.N., J.C. McCarty, Jr., and W.L. Parrott. 1990a. Fruiting efficiency in cotton: Boll size and boll set percentage. Crop Sci. 30:857-860.

Jenkins, J.N., J.C. McCarty, Jr., and W.L. Parrott. 1990b. Effectiveness of fruiting sites in cotton: Yield. Crop Sci. 30:365-369.

Jenkins, J.N., and J.C. McCarty. 1995. Useful tools in managing cotton production: End of season plant maps. Mississippi Agriculture and Forestry Exp. Stn. Bull. 1024.

Jones, M.A., and R. Wells. 1998. Fiber yield and quality of cotton grown at two divergent population densities. Crop Sci. 38:1190-1195.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen-inorganic forms. p. 643-698. *In* Methods of soil analysis. Agronomy Monograph 9, Part 2, 2nd ed. Page, Miller, and Keeney, eds. Am. Soc. Agron., Madison, WI.

Kerby, T.A., M. Keely, and S. Johnson. 1987. Growth and development of Acala cotton. Univ. of Calif. Agric. Exp. Stn. Bull. 1921.

Kerby, T.A., and G. Ruppenicker. 1992. Canopy architecture and fiber quality variation by branch location. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 3:1069.

Kerby, T.A., and K.D. Hake. 1996. Monitoring cotton's growth. p. 335-355. *In* Cotton production manual. S.J. Hake, T.A. Kerby, and K.D. Hake, eds. Univ. of California Division of Agriculture and Natural Resources, Oakland, CA. pub. 3352.

Kerby, T.A., S.J. Hake, K.D. Hake, L.M. Carter, and R.H. Garber. 1996. Seed quality and planting environment. p. 203-209. *In* Cotton production manual. S.J. Hake, T.A. Kerby, and K.D. Hake, eds. Univ. of California Division of Agriculture and Natural Resources, Oakland, CA. pub. 3352.

Kerby, T., B. Hugie, K. Howard, M. Bates, J. Burgess, and J. Mahaffey. 2000. Fiber quality comparisons among varieties for conventional, Bollgard, and Roundup Ready versions. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:484-488.

Kerby, T., D. Albers, K. Lege', and J. Burgess. 2002. Changes in yield and fiber quality due to variety grown. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. Available on: cdrom.

Kuepper, G. 2003. Foliar fertilization. Appropriate Technology Transfer for Rural Areas (ATTRA). Available at: http://attra.ncat.org/attra-pub/pdf/foliar.pdf.

Lancaster, J.D., and Z.A. Savatli. 1965. Foliar application of phosphorus for cotton. Mississippi State Univ. Agric. Exp. Stn. Bull. 708.

Landivar, J.A. 1993. A plant map analysis program for cotton – PMAP. Texas Agriculture Exp. Sta. MP. 1740. Texas Agric. Exp. Stn., College Station, TX.

Leffler, H.R. 1983. Population density affects the development of plant structure and yield. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:45.

Lege', K.E., T.A. Kerby, D.A. Albers, and T.R. Speed. 2001. Yield and fiber quality comparisons between transgenic and conventional varieties. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:405-408.

Makhdum, M., M. Malik, S. Din, and F. Chaudhry. 2001. Effect on growth, yield, and fibre quality of two cotton cultivars. J. Res. Sci. Multan, Pakistan. 12:140-146.

Mauney, J.R. 1986. Vegetative growth and fruit development. p. 27. *In* Cotton physiology. J.R. Mauney and J.McD. Stewart, eds. The Cotton Foundation. Memphis, TN.

McConnell, J.S., W.H. Baker, and R.C. Kirst, Jr. 1998. Soil and plant nutrition: Yield and petiole nitrate concentrations of cotton treated with soil-applied and foliar-applied nitrogen. J. Cotton Sci. 2:143-152.

Microsoft Corporation. 1985-2001. Microsoft Excel 2002 for Windows, Release 10.4302.4219-SP-2. Microsoft Corporation. Redmond, WA.

Milliken, G.A., and D.E. Johnson.1992. Analysis of messy data vol. 1: Designed experiments. Chapman and Hall. New York, NY.

Milliken, G.A., and D.E. Johnson. 2002. Analysis of messy data vol. 3: Analysis of covariance. Chapman and Hall, CRC Press. Boca Raton, FL.

Moser, H.S., W.B. McCloskey, and J.C. Silvertooth. 2001. Performance of transgenic cotton varieties in Arizona. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:420-423.

Mullins, G.L., and C.H. Burmester. 1990. Dry matter, nitrogen, phosphorus, and potassium accumulation by four cotton varieties. Agron. J. 82:729-736

NASS, USDA Agricultural Statistics. 2002. Field crops: Final estimates 1997-2002. Available at: http://www.usda.gov/nass/pubs/histdata.htm.

Nelson, W.L. 1949. The effect of nitrogen, phosphorus, and potash on certain lint and seed properties of cotton. Agron. J. 41:289-293.

Ohlendorf, B.L., P.A. Rude, J.K. Clark, and M.L. Flint. 1996. Integrated pest management for cotton, 2nd ed. p. 17-23. Univ. of California Division of Agriculture and Natural Resources, Oakland, CA. pub. 3305.

Olsen, L.C., and R.P. Bledsoe. 1942. The chemical composition of the cotton plant and the uptake of nutrients at different stages of growth. Georgia Agric. Exp. Stn., Athens, GA. Bull. 222.

Oosterhuis, D.M., F.M. Bourland, N.P. Tugwell, and M.J. Cochran. 1996. Terminology and concepts related to COTMAN crop monitoring system. Ark. Agric. Exp. Stn. Spec. Rep. 174, Fayetteville, AR.

Ott, R.L., and M. Longnecker. 2001. An introduction to statistical methods and data analysis, 5th ed. p. 204-220. Wadswoth Group. Pacific Grove, CA.

Parvin, D., and R. Atkins. 1997. Comparative value per acre by fruiting site for two plant growth regulators. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:336-338.

Peferoen, M. 1997. Insect control with transgenic plants expressing *Bacillus thuringensis* crystal protein. p. 21-48. *In* Advances in insect control: The role of transgenic plants. N. Carozzi and M. Koziel, eds. Taylor & Francis, Bristol, PA.

Phene, C.J. 1999. Subsurface drip irrigation part 1: Why and how?. Irrigation Journal. (April) Available at: http://www.greenmediaonline.com/ij/1999/0499/499sub.asp.

Reddy, V.R., Z. Wang, and K.R. Reddy. 1997. Growth responses of cotton to aldicarb and temperature. Environ. Exp. Bot. 38:39-48.

ReJesus, R.M., J.K. Greene, M.D.Hammig, and C.E. Curtis. 1997. Economic analysis of insect management strategies for transgenic Bt cotton production in South Carolina. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:247-251.

Sabbe, W.E., and L.J. Zelinski. 1990. Plant analysis as an aid in fertilizing cotton. p. 469-493. *In* Soil testing and plant analysis, 3rd ed. R.L. Westerman, ed. SSSA Book Series 3. SSSA, Madison, WI.

Sadras, V.O. 1995. Compensatory growth in cotton after loss of reproductive organs. Field Crops Res. 40:1-18.

SAS Institute. 1999-2000. The SAS System for Windows, Release 8.1. SAS Institute Inc. SAS Campus Dr., Cary, NC.

Satterthwaite, F.E. 1946. An approximate distribution of estimates of variance components. Biometrics 2:110-114.

Smith, R.B., J.D. Oster, and C.J. Phene. 1991. Subsurface drip produced highest net return in Westlands area study. Calif. Agric. 45(2):8-10.

SPSS. 1989-2001. SPSS for Windows, Release 11.0.1. SPSS Inc. Chicago, IL.

Taiz, L., and E. Zeiger. 1998. Plant physiology, 2nd ed. p. 110-113. Sinauer Associates, Inc. Sunderland, MA.

USDA, Agricultural Marketing Service, Cotton Division. 1993. The classification of cotton. USDA-ARS. pub. 566.

Williford, J.R., W.R. Meredith, Jr., and W.S. Anthony. 1988. Production, harvesting, and ginning to preserve color and grade. Proc. Beltwide Cotton Conf., National Cotton Council Am., Memphis, TN. 1:60-62.

Wilson, P., H. Air, and G. Snider. 1984. Drip irrigation for cotton. USDA Economic Research Center. Agricultural Economic Report no. 517.

Wullschleger, S.D., and D.M. Oosterhuis. 1990. Photosynthetic carbon production and use by developing cotton leaves and bolls. Crop Sci. 30:1259-1264.

APPENDIX A

CROP PRODUCTION PRODUCTS USED IN

2001 AND 2002 FIELD STUDY

The following products were used at the rates specified for control of the indicated pests.

Early Season

Thrips (*Thrips tabaci*)	Temik® 15G – aldicarb: 4.48 kg ha^{-1} [2-methyl-2-(methylthio)propionaldehyde *O*-(methylcarbamiyl)]
	Gaucho® 480 – imidacloprid: 5.2 ml kg^{-1} 1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine
Pythium spp. and *Rhizoctonia solani*	Ridomil® Gold PC – pentachloronitrobenzene (PCNB): 8.97 kg ha^{-1} (R)-2-[(2,6-dimethylphenyl)-methoxyacetylamino]propionoic acid methyl ester
Broadleaf weeds (primarily *Ipomea sp.*)	Cotoran® 4L – fluometuron: 4.68 L ha^{-1} 1,1 dimethyl-3-(α,α,α-trifluoro-*m*-tolyl)unrea
Cotton Aphid (*Aphis gossypii*)	Trimax™ – imidacloprid: 0.07 L ha^{-1} 1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine
Cotton Fleahopper (*Pseudatomoscelis seriatus*)	Trimax™ – imidacloprid: 0.07 L ha^{-1} 1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine

Overwintered Boll Weevil (*Anthonomus grandis*)	Guthion® 2L – azinphosmethyl: 1.17 L ha^{-1} *O,O*-dimethyl *S*-[(4-oxo-1,2,3-benzotrian-3(4*H*)-yl)methyl] phosphorodithioate
	Capture® 2EC – bifenthrin: 0.30 L ha^{-1} (2 methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
	Karate® with Zeon™ Technology – lambda-cyhalothrin: 0.30 L ha^{-1} [1α(*S**),3α(*Z*)]-(±)-cyano-(3-phenoxy-phenyl)methyl-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclo-propanecarboxylate
Mid to Late Season	
Boll Weevil (*Anthonomus grandis*)	Guthion® 2L – azinphosmethyl: 1.17 L ha^{-1} *O,O*-dimethyl *S*-[(4-oxo-1,2,3-benzotrian-3(4*H*)-yl)methyl] phosphorodithioate
	Capture® 2EC – bifenthrin: 0.30 L ha^{-1} (2 methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
	Karate® with Zeon™ Technology – lambda-cyhalothrin: 0.30 L ha^{-1} [1α(*S**),3α(*Z*)]-(±)-cyano-(3-phenoxy-phenyl)methyl-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropane carboxylate
	Vydate® C-LV – oxamyl: 0.78 L ha^{-1} [methyl *N*,*N*'-dimethyl-*N*-[(methyl-carbamoyl)oxy]-1-thiooxamimidate]
Cotton Aphid (*Aphis gossypii*)	Bidrin® 8 – dicrotophos: 0.44 L ha^{-1} Dimethyl phosphate of 3-hydroxy-*N*,*N*-dimethyl-*cis*-crotonamide

	Curacron® 8E – profenofos: 1.17 L ha^{-1} *O*-(4-bromo-2-chlorophenyl) *O*-ethyl-*S*-propyl phosphorothioate
	Provado® 1.6F – imidacloprid: 0.27 L ha^{-1} 1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine
	Centric® 40WG – thiamethoxam: 0.14 kg ha^{-1} 3-[(2-chloro-5-thiazolyl)methyl]tetrahydro-5-methyl-*N*-nitro-4*H*-1,3,5-oxadiazin-4-imine
Cotton Bollworm (*Heliothis zea*)	Curacron® 8E – profenofos: 0.88 L ha^{-1} *O*-(4-bromo-2-chlorophenyl) *O*-ethyl-*S*-propyl phosphorothioate
	Ammo® 2.5EC – cypermethrin: 0.37 L ha^{-1} and 0.15 L ha^{-1} in tank-mix (±) α-cyano (3-phenoxyphenyl)methyl (±) *cis*/*trans* 3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropane carboxylate
	Fury® 1.5EC – zeta-cypermethrin: 0.22 L ha^{-1} and 0.15 L ha^{-1} in tank-mix *S*-cyano (3-phenoxyphenyl)methyl (±) *cis*/*trans* 3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropane carboxylate
	Larvin® 3.2 – thiodicarb: 0.37 L ha^{-1} Dimethyl *N*,*N*'-[thiobis[(methylimino) carbonyloxy]]bis[ethanimidothioate]
Broadleaf weeds (primarily *Ipomea sp.*)	Caparol® 4L – prometryn: 2.34 L ha^{-1} 2,4-bis(isopropylamino)-6-(methylthio)-*S*-triazine
	Clean Crop® MSMA 6 Plus – MSMA: 0.31 L ha^{-1} monosodium acid methanearsonate

Annual grasses (primarily *Panicum texanum*)	Fusilade® DX – fluazifop-P-butyl: 0.88 L ha^{-1} Butyl (*R*)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoate
Plant Growth Regulators	PGR-IV® – 0.30 L ha^{-1} Mixture of indolebutyric acid and gibberellic acid
	Pix® Plus – mepiquat chloride: 0.44 L ha^{-1}, 0.58 L ha^{-1}, and 0.88 L ha^{-1} N,N-dimethylpiperidinium chloride
	Bacillus cerus, strain BP01
Harvest Aids	Dropp® 50WP – thidiazuron: 0.11 kg ha^{-1} N-phenyl-N'-1,2,3-thiadiazol-5-ylurea
	Def® 6 – tribufos: 0.58 L ha^{-1} and 0.94 L ha^{-1} *S*,*S*,*S*-tributyl phosphorotrithioate
	Cyclone® Max – paraquat dichloride: 1.46 L ha^{-1} 1,1'-dimethyl-4,4'-bipyridinium dichloride
	Leafless® – dimethipin and thidiazuron: 0.88 L ha^{-1} dimethipin: 2,3-dihydro-5,6-dimethyl-1,4-dithiin-1,1,4,4-tetraoxide thidiazuron: N-phenyl-N'-1,2,3-thiadiazol-5-ylurea
	Prep® – ethephon: 0.58 L ha^{-1} (2-chloroethyl) phosphonic acid

APPENDIX B

CROP PRODUCTION PRODUCTS USED IN

2003 GREENHOUSE STUDY

The following products were used for insect pests at the rates indicated.

Early Season

Overwintered Boll Weevil (*Anthonomus grandis*)	Guthion® 2L – azinphosmethyl: 1.17 L ha^{-1} *O*,*O*-dimethyl *S*-[(4-oxo-1,2,3-benzotrian-3(4*H*)-yl)methyl] phosphorodithioate
	Capture® 2EC – bifenthrin: 0.30 L ha^{-1} (2 methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
Spider Mites (*Tetranychus* spp.)	Avid® 0.15EC – abamectin: 1.09 and 0.90 L ha^{-1} Mixture of avermectins containing primarily Avermectin B1a and Avermectin B1b
	Sanmite® – pyridaben: 0.68 L ha^{-1} 2-tert-5-(4-tert-butylbenzyl-thio)-4-chloropyridazin-3(2H)-one
Thrips (*Thrips tabaci*)	Conserve® SC – spinosad: 0.64 L ha^{-1} Spinosyn A and Spinosyn D
	Talstar® GC Flowable – bifenthrin: 5.47 and 4.23 L ha^{-1} (2-methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate

Mid to Late Season

Boll Weevil (*Anthonomus grandis*)	Guthion® 2L – azinphosmethyl: 1.17 L ha^{-1} *O,O*-dimethyl *S*-[(4-oxo-1,2,3-benzotrian-3(4*H*)-yl)methyl] phosphorodithioate
	Capture® 2EC – bifenthrin: 0.30 L ha^{-1} (2 methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
Cotton Aphid (*Aphis gossypii*)	Bidrin® 8 – dicrotophos: 0.44 L ha^{-1} Dimethyl phosphate of 3-hydroxy-*N,N*-dimethyl-*cis*-crotonamide
	Fury® 1.5EC – zeta-cypermethrin: 0.22 L ha^{-1} *S*-cyano (3-phenoxyphenyl)methyl (±) *cis*/*trans* 3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropane carboxylate
	Talstar® GC Flowable – bifenthrin: 4.11 L ha^{-1} (2-methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
Spider Mites (*Tetranychus* spp.)	Akari™ 5SC – fenpyroximate: 2.44 L ha^{-1} Tert-butyl(E)-(-(1,3-dimethyl-5-phenoxypyrazol-4-ylmethyleneaminoxy)-p-toluate
	Avid® 0.15EC – abamectin: 0.82 L ha^{-1} Mixture of avermectins containing primarily Avermectin B1a and Avermectin B1b
	Sanmite® – pyridaben: 0.51 L ha^{-1} 2-tert-5-(4-tert-butylbenzyl-thio)-4-chloropyridazin-3(2H)-one

Thrips (*Thrips tabaci*)	Conserve® SC – spinosad: 0.62 L ha^{-1} Spinosyn A and Spinosyn D Talstar® GC Flowable – bifenthrin: 4.11 L ha^{-1} (2-methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
Silverleaf Whitefly (*Bemisia argentifolii*)	Marathon® II – imidacloprid: 0.19 L ha^{-1} 1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine
Cotton Bollworm (*Heliothis zea*)	Curacron® 8E – profenofos: 0.88 L ha^{-1} *O*-(4-bromo-2-chlorophenyl) *O*-ethyl-*S*-propyl phosphorothioate Fury® 1.5EC – zeta-cypermethrin: 0.22 L ha^{-1} and 0.15 L ha^{-1} in tank-mix *S*-cyano (3-phenoxyphenyl)methyl (±) *cis*/*trans* 3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropane carboxylate
Plant Growth Regulators	PGR-IV® – 0.30 L ha^{-1} Mixture of indolebutyric acid and gibberellic acid Pix® Plus – mepiquat chloride: 0.44 L ha^{-1}, 0.29 L ha^{-1}, and 0.44 L ha^{-1} N,N-dimethylpiperidinium chloride *Bacillus cerus*, strain BP01

VITA

Christopher Alan Hundley, son of Dennis Michael and Linda Sue Hundley, was born in Biloxi, Mississippi on July 12, 1977. He graduated from Judson High School in Converse, Texas on May 24, 1995. He received his Bachelor of Science degree in Agricultural Systems Management from Texas A&M University on December 16, 2000. Christopher entered the Master of Science program in January of 2001 to pursue a graduate degree in Agronomy. During his graduate career, he was employed as a Research Specialist with Biological Research Service, Inc. Additionally, as a Graduate Teaching Assistant at Texas A&M University, he taught several laboratory courses in the Biology and Soil and Crop Sciences departments. While completing graduate education, he met his wife, Leah Nicole Wall. They were married on May 31, 2003 and now reside at 725 San Saba Drive, College Station, TX 77845. Christopher currently holds a Research Specialist position with Bayer CropScience.